LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA23/24 | Balsall Common to Chelmsley Wood

River modelling of Bayley's Brook (at Marsh Farm and Lavender Hall Lane), the River Blythe Bypass, Shadow Brook and Hollywell Brook technical report (WR-004-018)

Water resources

November 2013

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Appendix WR-004-018

Environmental topic:	Water resources and flood risk assessment	WR
Appendix name:	Hydraulic modelling report	004
	River modelling of Bayleys Brook (at Marsh Farm and Lavender Hall Lane), the River Blythe Bypass, Shadow Brook and Hollywell Brook technical report)	018

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1 Introduction

1.1 Structure of the water resources and flood risk assessment appendices

1.1.1 The water resources and flood risk assessment appendices comprise a number of parts. The first of these is a route-wide appendix (Volume 5: Appendix WR-001-000).

1.1.2 A number of specific appendices for each community forum area are also provided. For the Balsall Common and Hampton-in-Arden (CFA23) and Birmingham Interchange and Chelmsley Wood area (CFA24) these are:

- water resources assessments (Volume 5: Appendix WR-002-023 and WR-002-024);
- flood risk assessments (Volume 5: Appendix WR-003-023 and WR-003-024);
- a hydrology report for the River Blythe and associated tributaries (Volume 5: Appendix WR-004-016);
- a hydraulic modelling report for the River Blythe and Bayleys Brook at Balsall Common viaduct (Volume 5: Appendix WR-004-017); and
- a hydraulic modelling report for the for Bayleys Brook (at Marsh Farm and Lavender Hall Lane), the River Blythe Bypass, Shadow Brook and Hollywell Brook (this appendix).

1.1.3 Maps referred to throughout the water resources and flood risk assessment appendices are contained in the Volume 5 water resources map book.

1.2 Scope of this assessment

1.2.1 Hydraulic models were constructed to enable an assessment of a) the baseline "as-is" condition and b) with the Proposed Scheme included, to allow for review of impacts on flood risk. In order to assess the scheme the following has been undertaken:

- model a range of return periods from 50% AEP to 1% AEP plus climate change for the pre- and post-development situations to ascertain peak flood levels and flood extent;
- develop mitigation options for post-development; and
- inform land required for the scheme.

1.3 Location

1.3.1 This report focuses on CFA23 Balsall Common and Hampton-in-Arden and Birmingham Interchange and Chelmsley Wood area (CFA24). The areas of consideration are shown in Figure 1 and Figure 2.

Figure 1: Balsall Common and Hampton-in-Arden

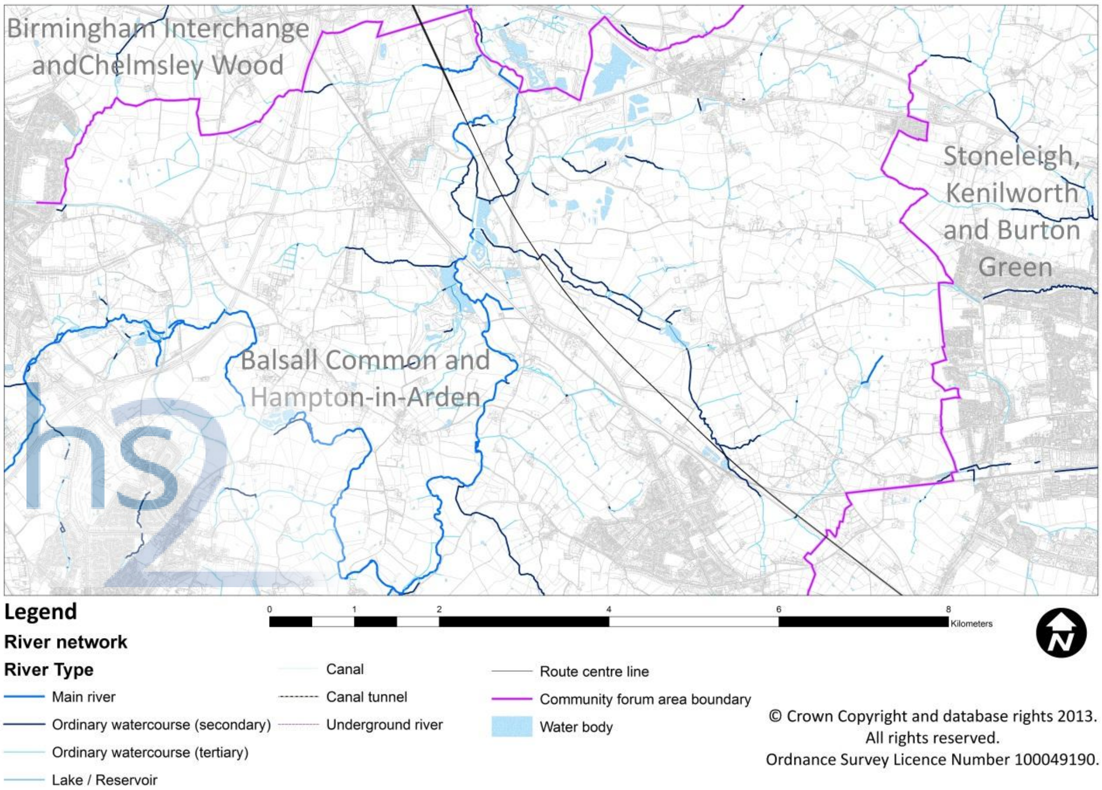
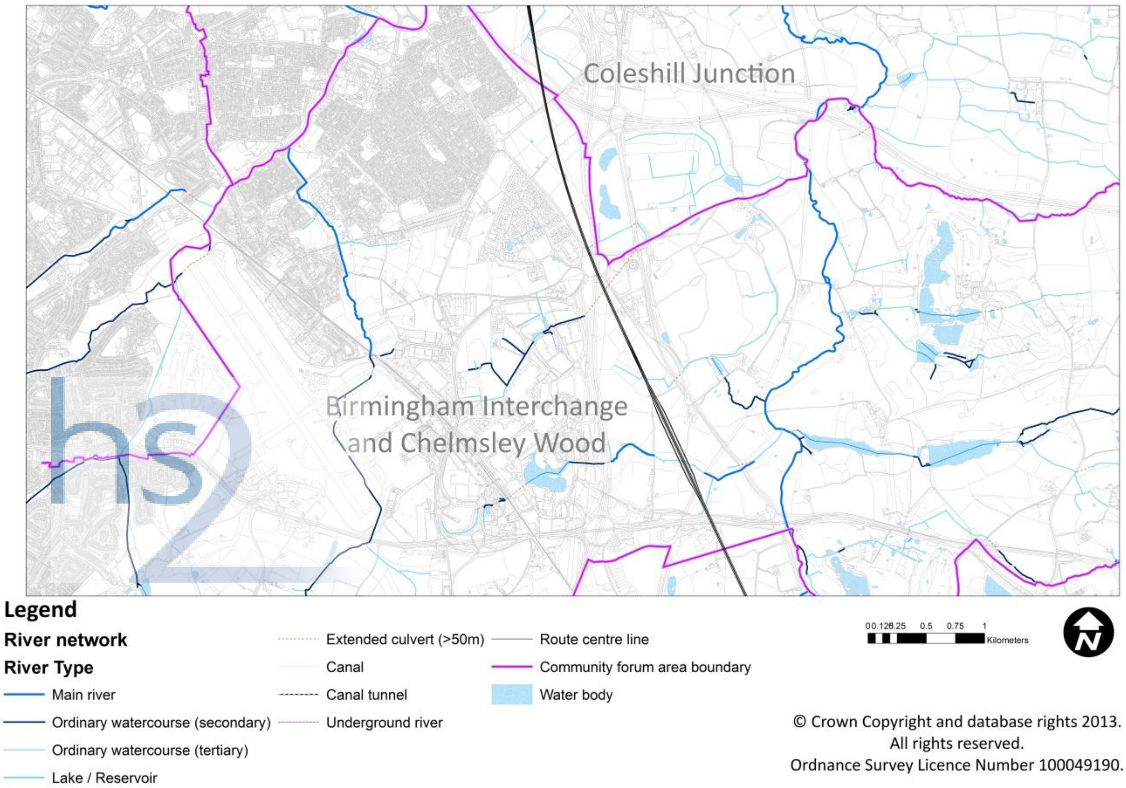


Figure 2: Birmingham Interchange and Chelmsley Wood



2 General Modelling

2.1 Introduction

2.1.1 The impact on flood risk due to the Proposed Scheme has been reviewed and options to mitigate increase in flood risk have been developed. The Proposed Scheme includes the main line, additional bridges and diversions of rivers and is detailed in the flood risk assessments (FRAs) (Volume 5: Appendices WR-003-023 and WR-003-024).

2.1.2 This report outlines the hydraulic modelling of four watercourse crossings within CFA23 and CFA24 areas, namely the Bayleys Brook and the River Blythe Bypass, Shadow Brook and Hollywell Brook.

2.2 Input data

2.2.1 The following information was used to develop the proposed hydraulic models:

- topographic survey (200mm grid resolution laser interferometry detection and ranging (LiDAR) survey, in digital terrain model and digital surface model format) and associated aerial photography;
- Ordnance Survey MasterMap (Ordnance Survey, 2012): MasterMap (vector) data features in the MasterMap data for the entire area of interest were last verified between 2001 and 2012;
- aerial imagery (Geostore, 2012): Provided at 25cm resolution and of varying collection dates prior to 2012;
- Environment Agency flood map data: flood zone 2, flood zone 3, defences, storage areas; and
- site visits were made to obtain an overview of key features such as roughness and notable features. Where there were existing hydraulic structures, an estimation of sizing was also undertaken where accessible.

2.3 Model limitations and further development

2.3.1 The model is intended to assess flood levels within the watercourse in the vicinity of the Proposed Scheme and determine the impact of the proposed development on flood levels and flood risk. The accuracy of the model is limited by the available survey information which is 0.25m resolution LiDAR. No supplementary topographic surveys have been obtained.

2.3.2 Further work is recommended to improve the model for the detailed design stage including:

- a detailed survey of the channel cross sections to supplement the LiDAR representation of the floodplain;
- a detailed walkover of the watercourse reach and improved assessment of roughness characteristics for both channel and floodplain;
- a detailed survey of all culverts, bridges and hydraulic structures; and

- improved assessment of boundary conditions where watercourses are tributaries of the River Blythe and outfall to a section of the Blythe not modelled as part of the Proposed Scheme. Where the River Blythe has been modelled there are also similar modelling limitations that could impact on boundary conditions.

2.3.3 The proposed models represent the watercourse main channel and rural floodplains with a level of detail deemed sufficient to establish the flood risk impact for pre and post-development scenarios for a range of return periods thus enabling an assessment of the impact of the Proposed Scheme.

3 Shadow Brook

3.1 Introduction

3.1.1 The hydraulic models cover a localised reach of the Shadow Brook which is a main river and tributary of the River Blythe. The section of watercourse modelled extends from grid reference 420803, 282378 upstream of the existing Diddington Lane to grid reference 421569, 282513 at the confluence with the River Blythe; a total reach length of approximately 1km around the proposed structure and an upstream semi-rural catchment area of 4.4km².

3.1.2 The Proposed Scheme interacts with the Shadow Brook at approximate grid reference 421134, 282366 with the route passing over Shadow Brook on a 19m twin span bridge.

3.2 Hydrology

Derivation of Inflows

3.2.1 A preliminary hydrological investigation has been undertaken in order to understand the magnitude of flows generated by the catchment up to a point a short distance downstream the proposed crossing point of the Proposed Scheme.

3.2.2 The catchment is semi-rural. The flows generated by the ReFH spreadsheet are shown in Table 1 below.

Table 1: Peak flow calculation results using ReFH

Annual Exceedence Probability (AEP)	Flow (m^3/s)
50%	1.46
20%	1.93
10%	2.31
5%	2.69
2%	3.29
1.33%	3.59
1%	3.83
1% AEP+20%	4.59
1% ARP+30%	4.98
0.1%	6.86

3.3 Hydraulic models

Overview

3.3.1 1D steady state models (HEC-RAS) were used to represent the watercourse main channels and rural floodplains for the pre- and post-development scenarios and a range of storm events with return periods of 50%, 20%, 10%, 5%, 2%, 1% and 0.1% AEP.

3.3.2 A 1D steady state model was considered appropriate for this river reach due to the relatively uniform, narrow floodplain. This choice of model allows the representation of the main features present in the area of interest and the estimation of their effects on extreme water levels. The main features in the modelled extent are:

- water levels and conveyance along the Shadow Brook, taking into account the channels' geometry and roughness;
- water levels and conveyance across the river's floodplains, taking into account ground levels, land uses and obstructions to flow (e.g. road embankments, buildings, etc.); and
- impact on water levels and flood flow conveyance of the Proposed Scheme infrastructure (refer to Section 3.5).

3.3.3 The model has also been run in an unsteady state condition to determine the potential increase in pass forward flow associated with the removal of the Diddington Lane culvert. All flood levels and assessment of flood risk impact from the Proposed Scheme crossing are discussed in terms of the steady state model.

3.4 Baseline model

3.4.1 All models are located within the Shadowbrookv3.prj file.

Table 2: Model titles

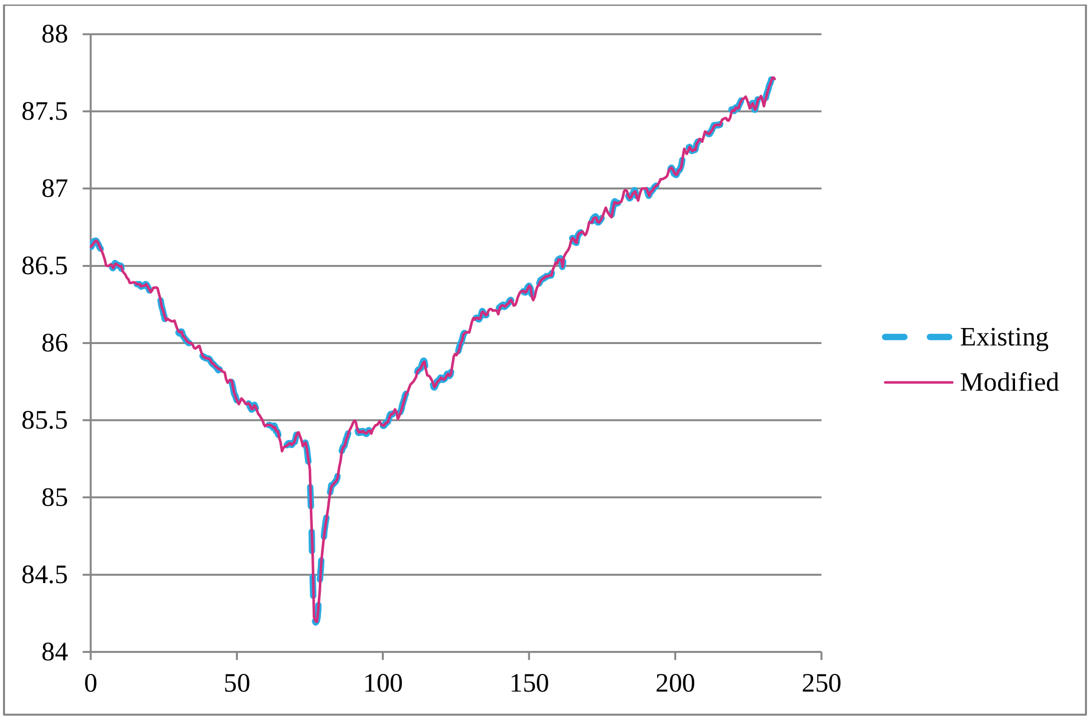
Model Title	Geometry File Title
Baseline	Baselinev2
Post Development Model	Post Development Modelv2

Topography

3.4.2 LiDAR data (refer to Section 2.2) was used to obtain ground levels across the reach extent. Cross sections were derived from LiDAR data inserted into ArcGIS as a raster image and the number of points in each cross section adjusted to comply with HEC-RAS's 500 station maximum limit. Road deck information for Diddington Road was also obtained using the same method.

3.4.3 The reduction in station points has been achieved without losing definition of either the floodplains or channel. This was possible due to the relatively short cross section lengths and the high resolution of the LiDAR data, enabling station points to be removed without significantly altering the geometric shape of floodplain or channel. A typical representation of the cross sections showing the before and after scenarios are included below for information.

Figure 3: Typical cross section showing reduced station data



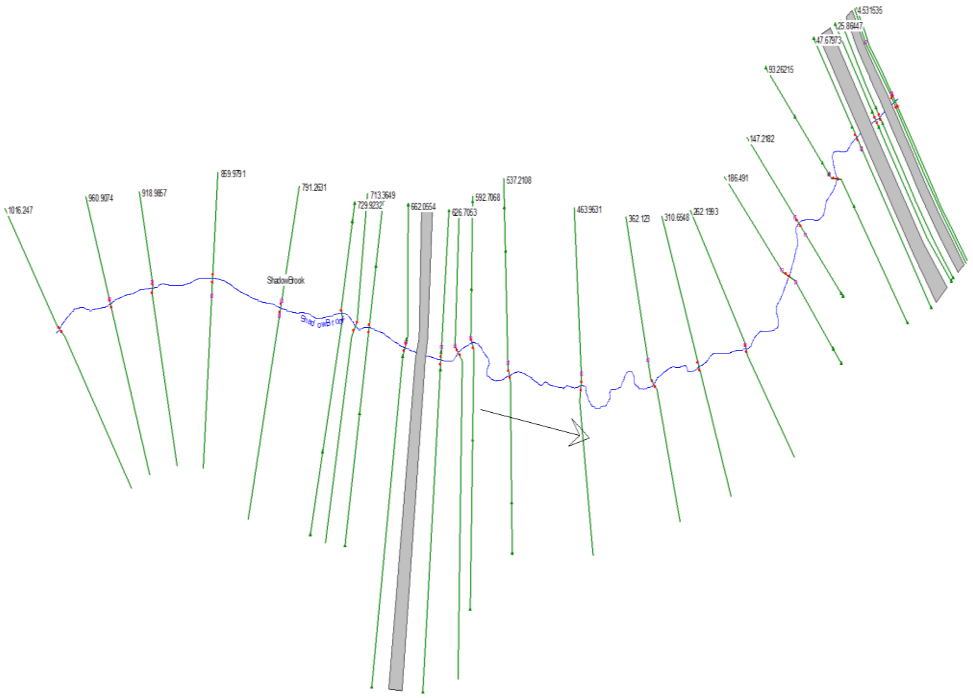
3.4.4 All field boundaries are assumed to enable conveyance of flood flows.

Cross section location

3.4.5 Cross section locations were selected in relation to obstructions to be modelled including an existing culvert and Shadow Brook underbridge. For the baseline model additional cross sections were inserted to the model using the internal bridge cross section module with all obstructions such as road deck and piers removed.

3.4.6 Cross sections locations are shown in Figure 4.

Figure 4: Cross section locations



Land use and roughness coefficients

3.4.7 Roughness coefficients were specified as Manning's 'n' values. Site observations were not possible for much of the reach and global roughness values were applied. Ordnance Survey MasterMap data and aerial photography was used to establish land uses and manning roughness values applied to suit.

Ineffective flow areas

3.4.8 Ineffective flow areas were applied on the upstream and downstream side of culverts and bridges to represent areas not conveying flow due to upstream or downstream restrictions.

Downstream boundary condition

3.4.9 The proposed baseline model assumes a 'normal depth' level-flow relationship as a downstream boundary condition for all flows. Second model runs of the 1% AEP plus climate change (cc) and 0.1% AEP flows have been undertaken using flood levels from the River Blythe as a downstream boundary condition. The Environment Agency's flood mapping identifies an approximate 1% AEP flood level of 83.92m and 0.1% AEP flood level of 84.35m at the confluence with the River Blythe.

3.4.10 This limitation on the boundary condition will impact on the accuracy of predicted flood levels in the downstream reach of the model and a sensitivity analysis has been undertaken to demonstrate how varying the boundary condition might impact on assessing the impact of the Proposed Scheme crossing. The sensitivity analysis has been extended to lower return periods as they would be equally affected by the uncertainty regarding the existing culvert dimension.

Table 3: Boundary conditions

AEP	Boundary condition
50%, 20% 10%, 5% & 2%	Normal Depth
1%	83.89m AOD
1% AEP + 20%, 0.1% AEP	84.35m AOD

Runtime parameters and model performance

3.4.11 The default HEC-RAS values were used in all simulations. Expansion and contraction coefficients were set to the default of 0.3 and 0.1 respectively.

3.4.12 The nature of the river reach has resulted in significant variation in cross sections leading to warnings regarding the large change in conveyance between upstream and downstream cross sections.

Baseline model results

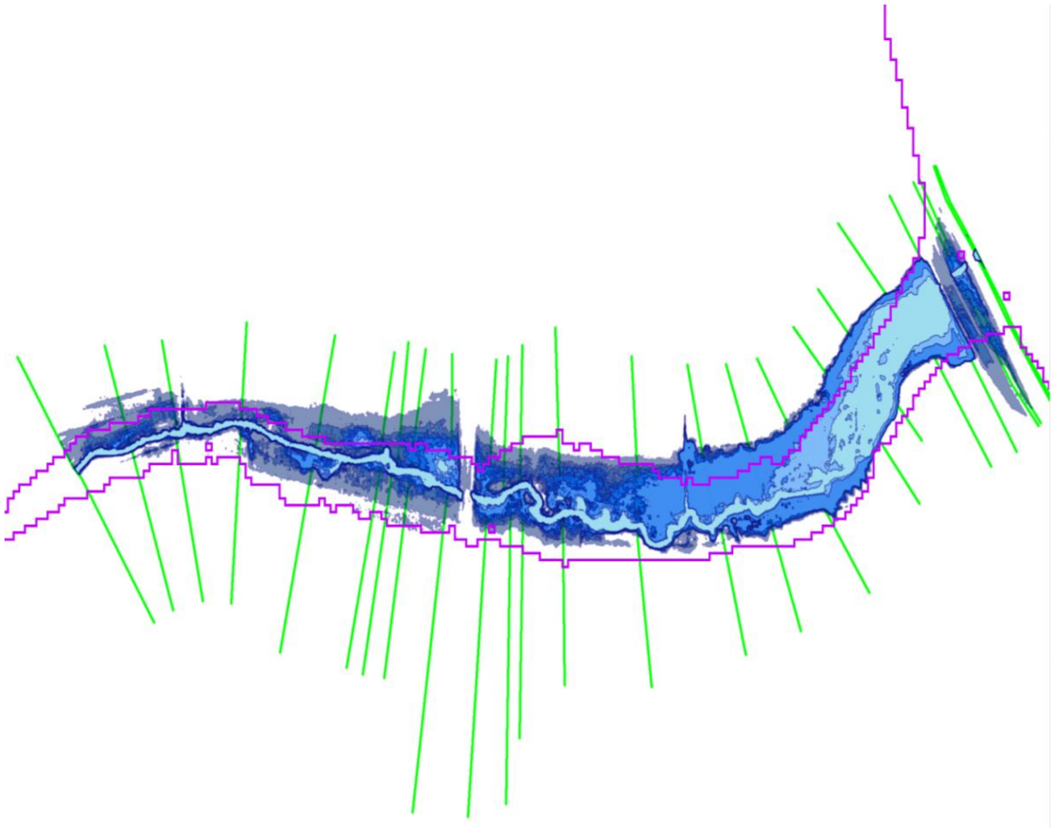
3.4.13 The baseline model was run for the 50%, 20%, 10%, 5%, 2%, 1% and 0.1% AEP flows. The estimate flood levels and flood extents are shown in Table 4.

Table 4: Baseline model results

AEP	Estimated level downstream of existing Diddington Road crossing XS 626	Estimated level upstream of existing Diddington Road crossing XS 662	Estimated level upstream of Shadow Brook underbridge XS 713
50%	84.72	84.853	84.96
20%	84.81	84.931	85.047
10%	84.869	84.997	85.114
5%	84.919	85.059	85.176
2%	84.969	85.141	85.259
1%	85.009	85.213	85.326
1% AEP +20%	85.055	85.312	85.413
0.1%	85.134	85.688	85.720

3.4.14 The floodplain mapping from the HEC-RAS model indicates a slightly narrower floodplain in the upstream reach in comparison to the national flood risk mapping (NFRM) extents. The mapping is shown in Figure 5 below.

Figure 5: Flood mapping and NFR mapping

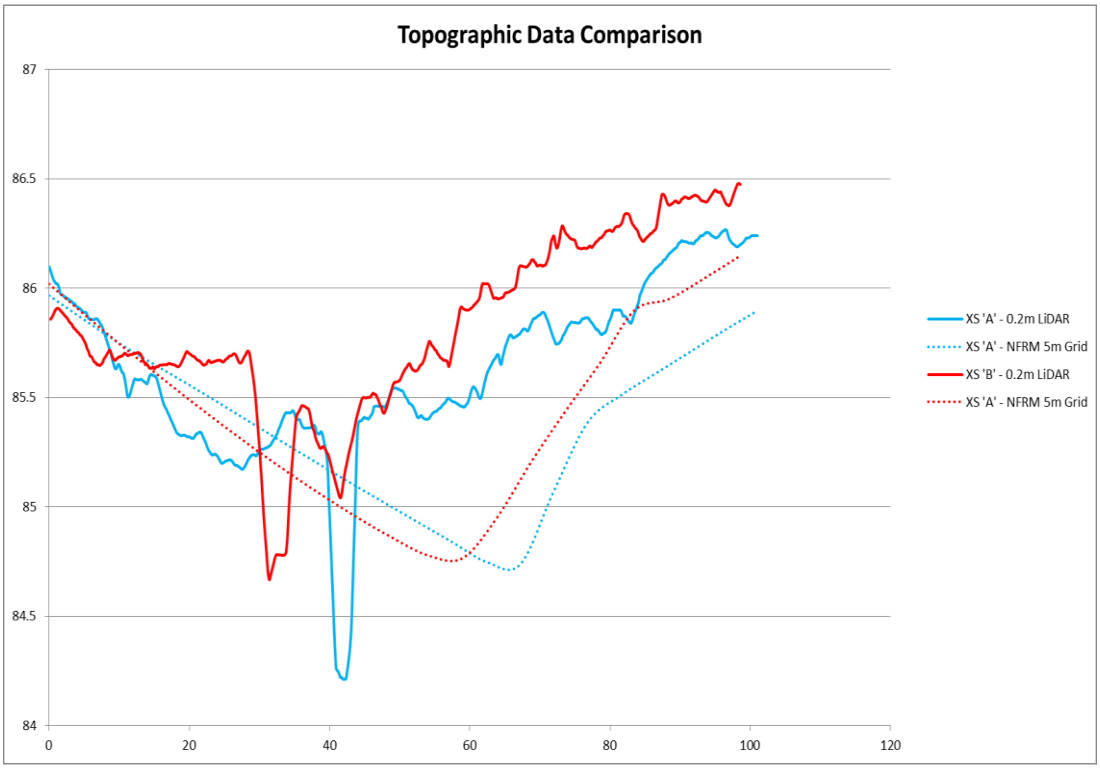


3.4.15 Two cross sections have been interpreted across the 0.2m LiDAR data used for hydraulic modelling and the 5m grid (which appears consistent with the data used to produce the NFRM). The cross sections are represented in Figure 6.

3.4.16 The cross sections show a clear discrepancy between the topography on the right bank of the watercourse valley which coincides with flood mapping extent (refer to Figure 5). The 5m grid would result in a much wider floodplain than the 0.2m LiDAR data for equivalent flood levels, with the increase extending mainly across the right bank as per the discrepancy in plan extent of flood mapping. The floodplain extent would decrease by more than 20m using the 0.2m LiDAR data.

3.4.17 Based on this assessment the difference in extent of floodplain is deemed to be associated with errors in topography data input rather than modelling errors.

Figure 6: Cross section comparison



3.5 Proposed Scheme development model

Overview

3.5.1 The Shadow Brook underbridge has been modelled as twin span (one 13.5m span and one 5.5m span) crossing, 45m in length. A single 2m wide pier separates the spans. The Shadow Brook underbridge is to be constructed with a skew through the embankment which orientates the structure in the natural direction of channel and floodplain flow. As such the bridge is modelled without a skew but embankments have been modelled within the cross sections where required to reflect the angle that the route crosses the floodplain. Ineffective flow areas have been incorporated at the relevant cross sections. The length of crossing is increased due to a new highway crossing over the watercourse and an increase in the vertical alignment with a resultant increase in earthworks footprint.

3.5.2 Cross sections for the baseline and post development models were kept consistent where possible. The length of the Shadow Brook underbridge and angle at which the embankments cross the floodplain required the removal of three crossings and the Diddington Lane Bridge to accommodate the longer structure.

Proposed Scheme model results

3.5.3 The post development model was run for the same flow and boundary condition events as the baseline model.

3.5.4 The proposed model results are shown in Table 5 for the cross section immediately upstream of the Proposed Scheme. A further comparison table of all cross sections are included at the end of this note.

3.5.5 Upstream of the route changes to peak levels show a significant decrease of up to 78mm for the 1% AEP + cc flood event. For lower return periods there is an estimated minor increase in flood levels by up to 12mm for the 50% AEP event and a negligible 6mm increase for the 20% AEP event. The decrease in flood level for the 1% AEP + cc event may result in a slight increase in pass forward flow which will be assessed using unsteady state model runs.

Table 5: Post development model results – Shadow Brook underbridge

AEP	Baseline estimated level upstream of Shadow Brook underbridge XS 713	Post development estimated level upstream of Shadow Brook underbridge XS 713	Maximum estimated change in peak water level
50%	84.960	84.972	0.012
20%	85.047	85.053	0.006
10%	85.114	85.109	-0.005
5%	85.176	85.158	-0.018
2%	85.259	85.224	-0.035
1%	85.326	85.275	-0.051
1% AEP + 20%	85.413	85.335	-0.078
0.1%	85.720	85.486	-0.234

3.6 Unsteady state modelling

Runtime parameters, model performance and unsteady computations

3.6.1 The default HEC-RAS simulation values were used in all simulations. Expansion and contraction coefficients were set to the default of 0.3 and 0.1 respectively.

3.6.2 The computational time step has been set to 30 seconds based on a Courant condition of one based on a cross section spacing of 35.

3.6.3 Model parameters have been left to default settings apart from the Theta weighting which was reduced to 0.6 while maintaining model stability.

3.6.4 The model has been run using a normal flow routine as Froude numbers are all less than one and therefore subcritical.

3.6.5 The model stability is good for both baseline and post development scenarios although some minor instability occurs at low flows across the A452 Kenilworth Road culverts.

Hydraulic rating curves

3.6.6 All hydraulic property curves have been inspected for the relevant structures and are considered acceptable for the analysis.

Historic data

3.6.7 There are no historic or observed flood levels or gauged data available for this reach.

Unsteady state model results

3.6.8 Table 6 shows the comparison between unsteady state and steady state model results for the 1% AEP + cc.

Table 6: Baseline unsteady state comparison

AEP	Steady state estimated level upstream of Shadow Brook underbridge XS 713	Unsteady state estimated level upstream of Shadow Brook underbridge XS 713	Maximum estimated change in peak water level
50%	84.960	84.965	0.005
10	85.114	85.118	0.004
5%	85.176	85.193	0.017
2%	85.259	85.258	-0.001
1%	85.326	85.323	-0.003
1% AEP + 20%	85.413	85.416	0.003

3.6.9 The unsteady model results are very close to the steady state results for all return period events. This is expected given the relatively linear nature of the floodplain with limited storage.

3.6.10 The flows have been analysed to determine the potential flow increase resulting from the lowering of upstream water levels. It should be noted that the modelling results do not include any replacement floodplain storage.

Figure 7: Shadow Brook hydrograph comparison at Blythe confluence

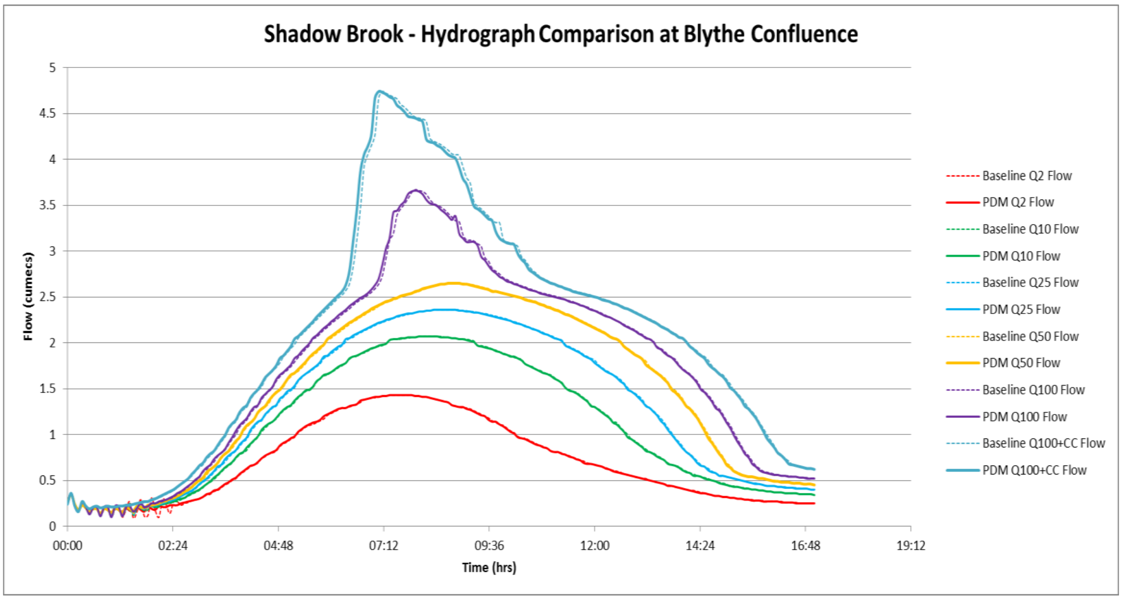
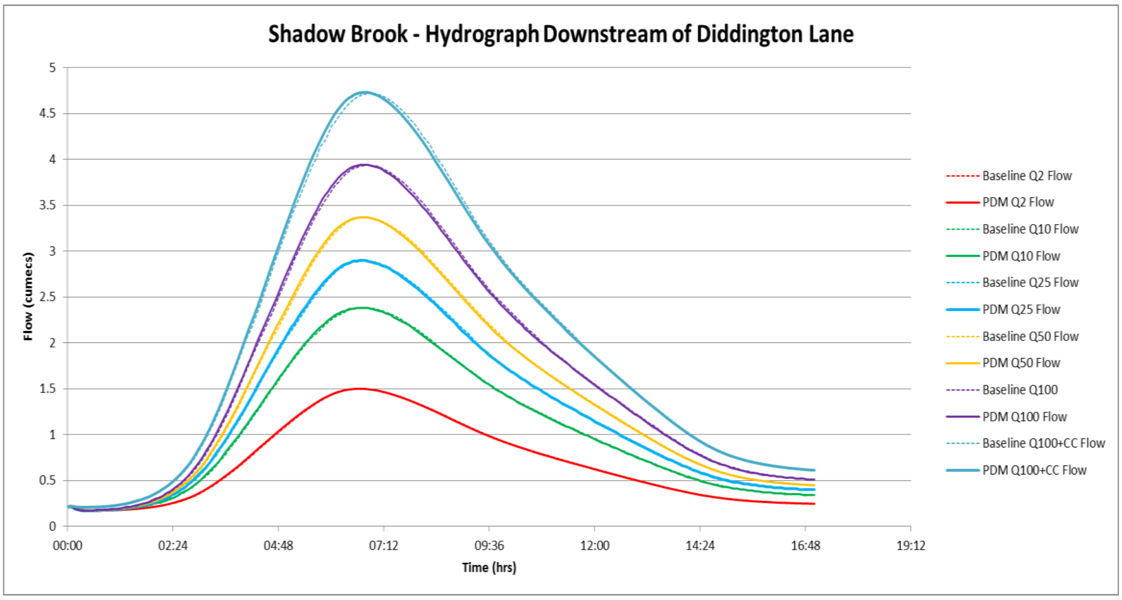


Figure 8: Shadow Brook hydrograph downstream of Diddington Lane



3.6.11 Results are provided downstream of Diddington Road and at the Blythe confluence. The results show no significant change in flows at either location. This is consistent with the flood levels which show only localised changes upstream of the route and almost no change on the downstream side.

3.7 Sensitivity testing

Overview

3.7.1 Given the absence of calibration data, surveyed levels of flooding or historic flood outlines for the modelled reach of the Shadow Brook, a range of sensitivity tests were undertaken for the most critical assumptions made during the model build. These are:

- roughness coefficients (sensitivity test 1);
- downstream boundary condition (sensitivity test 2); and
- blockage of proposed structure (sensitivity test 3).

3.7.2 Sensitivity test 1 was carried out for the 1% AEP plus climate change event, test 2 for the full range of flows and sensitivity test 3 was undertaken for the 0.1% AEP event and will also be used to provide design 0.1% AEP flood level for the Proposed Scheme. Results are presented in the following sections.

Roughness coefficients (sensitivity test 1)

3.7.3 The post development model's sensitivity to roughness coefficients was assessed by considering ±20% variations on the adopted Manning's 'n' values.

Table 7: Baseline model results

Sensitivity test	Flood level (upstream of Diddington Lane (1% AEP + CC) XS662
Modelled roughness values -20%	85.303
Modelled roughness values	85.334
Modelled roughness values +20%	85.370

3.7.4 With a 20% increase to Manning's 'n' values the estimate flood level shows an increase of only 36mm.

3.7.5 With a 20% decrease to Manning's 'n' values the estimate flood level shows a decrease of only 31mm.

3.7.6 Manning's roughness values will remain at the default chosen values as they are considered a reasonable approximation of roughness values within the catchment.

Downstream boundary condition (sensitivity test 2)

3.7.7 The baseline model's sensitivity to the downstream boundary condition has been assessed by considering variation in downstream boundary condition by ± 0.5m on 1% AEP + cc flood level on the River Blythe.

Table 8: Downstream boundary condition 1% AEP + cc levels – baseline model

Downstream boundary level	Flood Level XS626 (downstream of Diddington Lane crossing – 1% AEP+CC)	Flood Level XS662 (upstream of Diddington Lane crossing – 1% AEP+CC)	Change in water level
Normal depth	85.060	85.326	0.266
83.750	85.060	85.326	0.266
84.250	85.060	85.326	0.266
85.000	85.060	85.326	0.266

3.7.8 Varying the downstream boundary level by over 1m does not alter the flood levels at the Proposed Scheme alignment indicating that the proposed structure is a sufficient distance upstream so as to be unaffected by the boundary condition. A flood level of 85m AOD causes the A452 Kenilworth Road to overtop, indicating that the uncertainty regarding the A452 Kenilworth Road culvert dimensions will not impact on the flood level at the Shadow Brook underbridge.

3.7.9 Regardless of the above statement an additional sensitivity check has been undertaken on the impact of the A452 Kenilworth Road culvert dimensions which have been estimated from photos.

3.7.10 A range of culvert dimensions have been tested to determine the impact on upstream flooding.

Table 9: downstream boundary condition 1% AEP + cc levels – baseline cross section 5

A452 Kenilworth Road culvert dimension	**Flood level XS626 (downstream of Diddington Lane crossing – 1% AEP + CC)**
0.35m Diam. Culvert	85.060
1m x 1m Arch	85.060
4.5m span x 1.5m depth	85.060

3.7.11 Varying the A452 Kenilworth Road culvert dimension does not impact on flood levels at the downstream side of Diddington Road. The backwater effect of elevated water levels does not extend upstream even where the A452 Kenilworth Road is demonstrated to overtop.

Structure blockage (sensitivity test 3)

3.7.12 Blockage analysis has been performed to determine the risk to the Proposed Scheme during extreme flood events (0.1% AEP). Blockages have been applied to the proposed route alignment as follows:

3.7.13 2% or 10% blockage depth as appropriate to the bridge / viaduct structure by raising internal bridge cross sections by a level equal to 2% of depth at the cross section (approximately 25mm increase) and increasing the pier width by 2% of the flow top width (56m, equating to approximately 1.12m increase to the pier).

3.7.14 No blockage has been applied to the A452 Kenilworth Road culverts as the boundary condition sensitivity test has already shown that the backwater affect does not extend to the Shadow Brook underbridge.

Table 10: Downstream boundary condition

Model	**Flood level (upstream of Proposed Scheme (0.1% AEP)**
Post development model	85.475
Blockage analysis	85.500

3.7.15 Introducing a blockage to the Shadow Brook underbridge increases the upstream flood level by only 25mm.

3.8 Uncertainty

3.8.1 Flood levels upstream of the Proposed Scheme will be used to inform the design levels. An uncertainty factor will be applied to these levels, calculated using the fluvial freeboard guidance note, R&D technical report W187 published by the Environment Agency (2000)[1].

3.8.2 The levels used are from the first cross section upstream of the Shadow Brook underbridge and not the cross section used to report the baseline and post-development model differences.

Table 11: Proposed Scheme design flood levels – cross section 6

AEP	Modelled level	Uncertainty allowance	Design flood level
1% AEP + 20%	85.335	0.132	85.467
0.1% AEP (including blockage analysis)	85.500	0.196	85.696

[1] Kirdy, A.m. and Ash, J.R.V. (2000) Fluvial freeboard guidance note, R&D technical report WR187, Environment Agency, Mott MacDonald Ltd and Risk & Policy Analysts Ltd,

3.9 Model results tables

Table 12: Baseline model results table

Baseline								
Cross-section	**AEP**							
	50%	**20%**	**10%**	**5%**	**2%**	**1%**	**1%+cc**	**0.1%**
1016.247	85.692	85.796	85.863	85.92	85.998	86.061	86.134	86.291
960.9074	85.548	85.649	85.713	85.766	85.841	85.902	85.975	86.127
918.9857	85.463	85.561	85.626	85.676	85.747	85.805	85.878	86.032
859.9791	85.285	85.387	85.458	85.499	85.563	85.615	85.682	85.86
791.2631	85.111	85.201	85.268	85.321	85.397	85.459	85.539	85.779
729.9232	84.999	85.085	85.15	85.211	85.293	85.359	85.445	85.732
713.3649	84.96	85.047	85.114	85.176	85.259	85.326	85.413	85.72
698.9615	84.933	85.019	85.085	85.146	85.228	85.298	85.392	85.715
662.0554	84.853	84.931	84.997	85.059	85.141	85.213	85.312	85.688
626.7053	84.72	84.81	84.869	84.919	84.969	85.009	85.055	85.134
607.4755	84.647	84.737	84.795	84.841	84.874	84.91	84.954	85.044
592.7068	84.612	84.701	84.76	84.808	84.832	84.868	84.912	85
537.2108	84.465	84.552	84.611	84.655	84.69	84.72	84.756	84.833
463.9631	84.166	84.253	84.273	84.358	84.41	84.449	84.49	84.597
362.123	83.791	83.886	84.086	84.326	84.38	84.415	84.448	84.539
310.6548	83.676	83.801	84.06	84.32	84.373	84.407	84.438	84.525
262.1993	83.524	83.759	84.056	84.318	84.371	84.405	84.435	84.521
186.491	83.436	83.752	84.054	84.317	84.37	84.404	84.434	84.519
147.2182	83.426	83.75	84.054	84.317	84.37	84.403	84.433	84.517
93.26215	83.418	83.749	84.053	84.317	84.369	84.402	84.432	84.516
47.67973	83.41	83.745	84.051	84.314	84.366	84.399	84.428	84.509
25.86447	82.951	83.083	83.184	83.279	83.424	83.547	83.71	84.238
21.53509	82.938	83.073	83.176	83.273	83.42	83.544	83.707	84.237
4.531535	82.604	82.663	82.705	82.745	82.802	82.851	82.908	82.725
2.739648	82.601	82.66	82.703	82.744	82.802	82.852	82.911	82.675

Table 13: Post development model results table

Post development								
Cross-section	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**1%+cc**	**0.1%**
1016.247	85.692	85.796	85.862	85.919	85.997	86.06	86.133	86.29
960.9074	85.547	85.647	85.711	85.764	85.839	85.9	85.974	86.123
918.9857	85.462	85.559	85.622	85.672	85.744	85.802	85.876	86.022
859.9791	85.283	85.378	85.444	85.489	85.554	85.607	85.677	85.819
791.2631	85.105	85.194	85.257	85.311	85.381	85.438	85.51	85.669
729.9232	85.003	85.086	85.143	85.195	85.262	85.315	85.38	85.54
713.3649	84.972	85.053	85.109	85.158	85.224	85.275	85.335	85.486
698.9615	-	-	-	-	-	-	-	-
662.0554	-	-	-	-	-	-	-	-
626.7053	-	-	-	-	-	-	-	-
607.4755	84.648	84.739	84.795	84.842	84.875	84.91	84.953	85.036
592.7068	84.612	84.703	84.76	84.808	84.833	84.869	84.913	85
537.2108	84.465	84.552	84.611	84.655	84.69	84.72	84.756	84.833
463.9631	84.166	84.253	84.273	84.358	84.41	84.449	84.49	84.597
362.123	83.791	83.886	84.086	84.326	84.38	84.415	84.448	84.539
310.6548	83.676	83.801	84.06	84.32	84.373	84.407	84.438	84.525
262.1993	83.524	83.759	84.056	84.318	84.371	84.405	84.435	84.521
186.491	83.436	83.752	84.054	84.317	84.37	84.404	84.434	84.519
147.2182	83.426	83.75	84.054	84.317	84.37	84.403	84.433	84.517
93.26215	83.418	83.749	84.053	84.317	84.369	84.402	84.432	84.516
47.67973	83.41	83.745	84.051	84.314	84.366	84.399	84.428	84.509
25.86447	82.951	83.083	83.184	83.279	83.424	83.547	83.71	84.238
21.53509	82.938	83.073	83.176	83.273	83.42	83.544	83.707	84.237
4.531535	82.604	82.663	82.705	82.745	82.802	82.851	82.908	82.725
2.739648	82.601	82.66	82.703	82.744	82.802	82.852	82.911	82.675

Table 14: Baseline and post development model comparison

Comparison								
Cross-section	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**1%+cc**	**0.1%**
1016.247	0	0	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
960.9074	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.004
918.9857	-0.001	-0.002	-0.004	-0.004	-0.003	-0.003	-0.002	-0.01
859.9791	-0.002	-0.009	-0.014	-0.01	-0.009	-0.008	-0.005	-0.041
791.2631	-0.006	-0.007	-0.011	-0.01	-0.016	-0.021	-0.029	-0.11
729.9232	0.004	0.001	-0.007	-0.016	-0.031	-0.044	-0.065	-0.192
713.3649	0.012	0.006	-0.005	-0.018	-0.035	-0.051	-0.078	-0.234
698.9615		-	-	-	-	-	-	-
662.0554	-	-	-	-	-	-	-	-
626.7053	-	-	-	-	-	-	-	-
607.4755	0.001	0.002	0	0.001	0.001	0	-0.001	-0.008
592.7068	0	0.002	0	0	0.001	0.001	0.001	0
537.2108	0	0	0	0	0	0	0	0
463.9631	0	0	0	0	0	0	0	0
362.123	0	0	0	0	0	0	0	0
310.6548	0	0	0	0	0	0	0	0
262.1993	0	0	0	0	0	0	0	0
186.491	0	0	0	0	0	0	0	0
147.2182	0	0	0	0	0	0	0	0
93.26215	0	0	0	0	0	0	0	0
47.67973	0	0	0	0	0	0	0	0
25.86447	0	0	0	0	0	0	0	0
21.53509	0	0	0	0	0	0	0	0
4.531535	0	0	0	0	0	0	0	0
2.739648	0	0	0	0	0	0	0	0

4 Hollywell Brook

4.1 Introduction

4.1.1 The hydraulic models cover a localised reach of the Hollywell Brook which is a main river and tributary of the River Blythe. The section of watercourse modelled extends from grid reference 420253, 283716 upstream of Middle Bickenhill Lane to grid reference 421377, 283880 at the confluence with the River Blythe; a total reach length of 1.36km around the proposed structures and a semi-rural catchment area of 6km². The post development model has been extended further upstream to assess the flood compensation requirements at the Birmingham Interchange station.

4.1.2 The Proposed Scheme interacts with the Hollywell Brook between chainages 156+200 and 156+800 and incorporates the route alignment and Birmingham Interchange station.

4.2 Hydrology

Derivation of inflows

4.2.1 A preliminary hydrological investigation has been undertaken in order to understand the magnitude of flows generated by the catchment up to a point a short distance downstream the proposed crossing point of the route.

4.2.2 The catchment is semi-rural while also receiving drainage from the NEC. The upstream reach of Hollywell Brook is heavily attenuated by a man made retention lake (Pendigo Lake), built as part of the NEC drainage network. The hydrological assessment of this crossing does not take account of retention of flows within Pendigo Lake. A further iteration of the hydrology should be undertaken in future.

4.2.3 The flows generated by the ReFH spreadsheet are shown in Table 15 below.

Table 15: Peak flow calculation results using ReFH

Annual exceedence probability (AEP)	Flow (m^3/s)
50%	1.59
20%	2.10
10%	2.5
5%	2.92
2%	3.55
1.33%	3.88
1%	4.13
1% AEP + 20%	4.96
1% AEP + 30%	5.37
0.1%	7.40

4.3 Hydraulic models

Overview

4.3.1 1D steady state models (HEC-RAS) were used to represent the watercourse main channels and rural floodplains for the pre- and post-development scenarios and a range of storm events with AEPs of 1 in 50%, 20%, 10%, 5%, 2%, 1% and 0.1% AEP.

4.3.2 A 1D steady state model was considered appropriate for this river reach due to the relatively uniform, narrow floodplain. This choice of model allows the representation of the main features present in the area of interest and the estimation of their effects on extreme water levels. The main features in the modelled extent are:

- water levels and conveyance along the Hollywell Brook, taking into account the channels' geometry and roughness;
- water levels and conveyance across the river's floodplains, taking into account ground levels, land uses and obstructions to flow (e.g. road embankments, buildings, etc.); and
- impact on water levels and flood flow conveyance of the Proposed Scheme infrastructure (refer to Section 4.5).

4.4 Baseline model

4.4.1 All models are located within the Hollywellbrook.prj file.

Table 16: Model titles

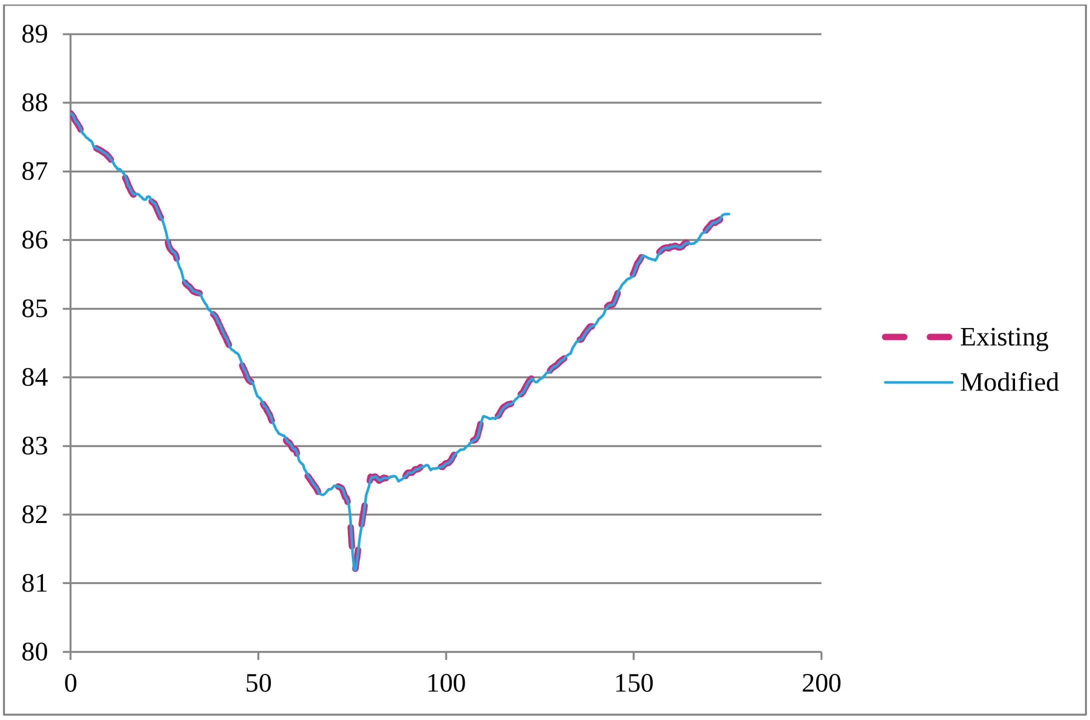
Model Title	Geometry File Title
Baseline	Baseline
Post Development Model	Post Development Model v4 – Culvert Removed

Topography

4.4.2 LiDAR data (refer to Section 2.2) was used to obtain ground levels across the reach extent. Cross sections were derived from LiDAR data inserted into ArcGIS as a raster image and the number of points in each cross section adjusted to comply with HEC-RAS's 500 station maximum limit. Road deck information was also obtained using the same method.

4.4.3 The reduction in station points has been achieved without losing definition of either the floodplains or channel. This was possible due to the relatively short cross section lengths and the high resolution of the LiDAR data, enabling station points to be removed without altering the geometric shape of floodplain or channel. A typical representation of the cross sections showing the before and after scenarios are included below for information.

Figure 9: Typical cross section showing reduced station data



Cross section location

4.4.4 Cross section locations were selected in relation to obstructions to be modelled including an existing culvert and the Hollywell Brook underbridge. For the baseline model additional cross sections were inserted to the model using the internal bridge cross section module with all obstructions such as road deck and piers removed.

4.4.5 Cross sections locations are shown in Figure 10.

Figure 10: Baseline cross section locations

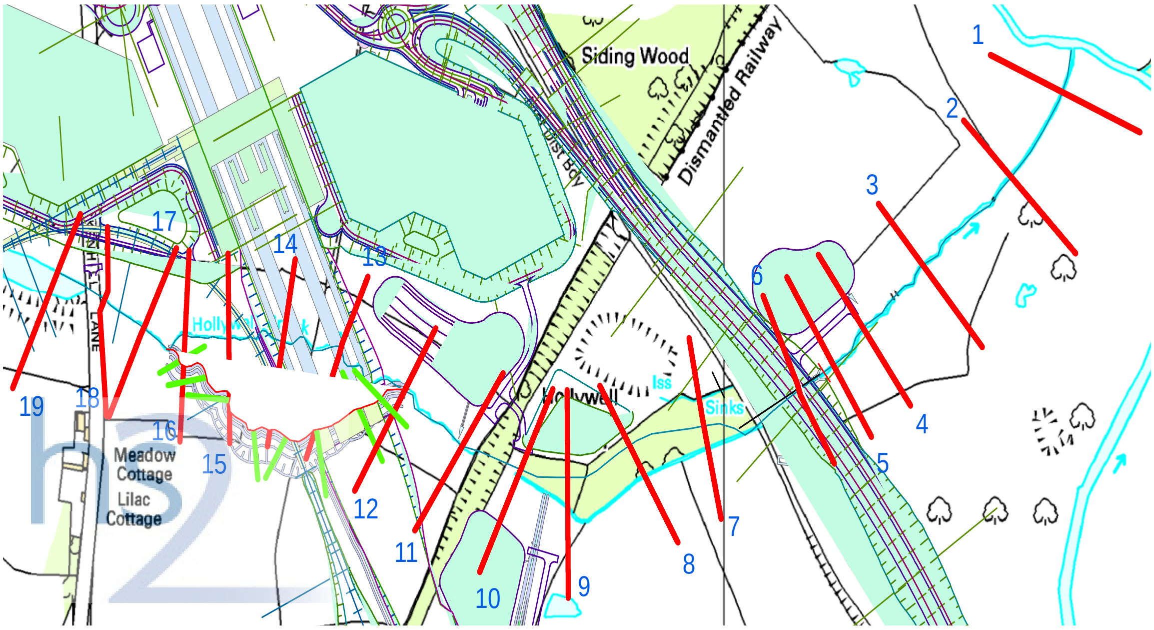
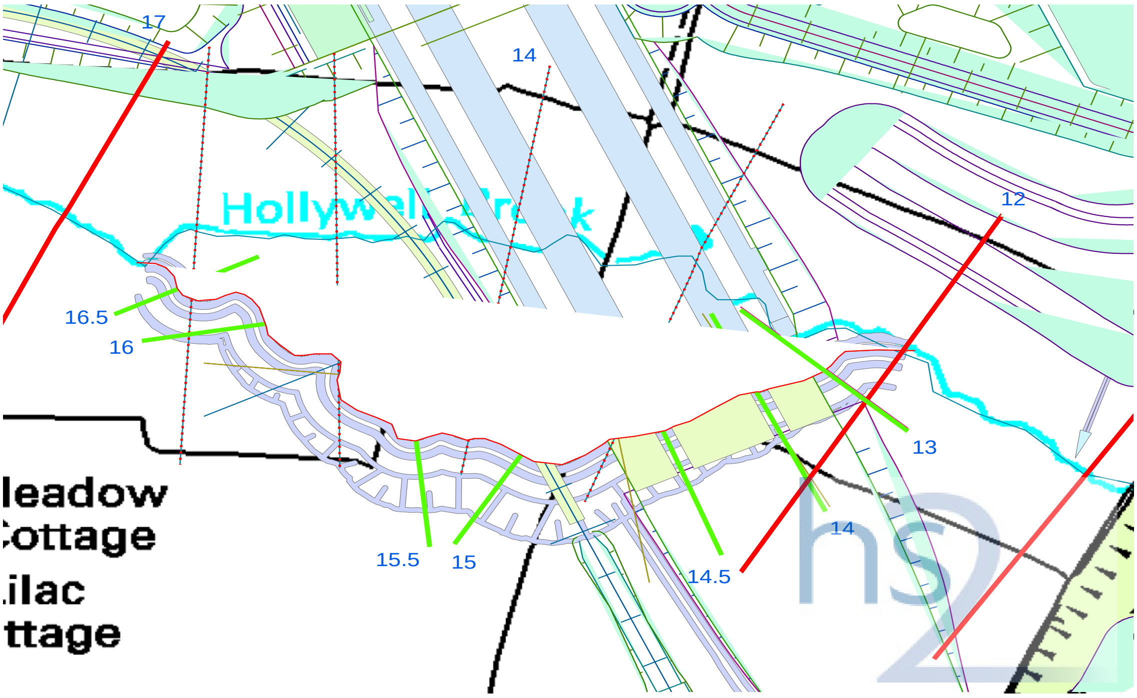


Figure 11: Post development channel diversion cross section locations



Land use and roughness coefficients

4.4.6 Roughness coefficients were specified as Manning's 'n' values. Site observations were not possible for much of the reach and global roughness values were applied. OS MasterMap data and aerial photography were used to establish land uses and manning roughness values applied to suit.

Ineffective flow areas

4.4.7 Ineffective flow areas were applied on the upstream and downstream side of culverts and bridges to represent areas not conveying flow due to upstream or downstream restrictions

Downstream boundary condition

4.4.8 The proposed baseline model assumes a 'normal depth' level-flow relationship as a downstream boundary condition for flows from 50% to 2% AEP. For the 1% and 0.1% AEP flows the boundary condition is set to the River Blythe flood level interpreted from Environment Agency flood maps as per those given in Table 17.

Table 17: Boundary conditions

AEP	Boundary condition
50%, 20%, 10%, 5% & 2%	Normal depth
1%	Fixed water level = 81.973m AOD
1% AEP + 20%, 0.1%	Fixed water level = 82.411m AOD

4.4.9 There is a degree of uncertainty regarding the flood mapping at the downstream section of the modelled reach due to the conservative approach to the downstream boundary conditions, combined with uncertainty regarding the River Blythe flood levels. To improve the flood mapping near to the Blythe confluence it will be necessary to model the appropriate section of the River Blythe.

4.4.10 No joint probability analysis has been undertaken on the Blythe and Blythe Bypass crossing and the likelihood of combined extreme flood events is probably unlikely given the relative catchment sizes. The application of 1% and 0.1% AEP flood levels for the boundary condition is likely to be a conservative assessment. A sensitivity analysis has been undertaken on the boundary condition applied for the 1% AEP + 20% climate change flow to determine the sensitivity of inaccuracy in existing flood levels.

Runtime parameters and model performance

4.4.11 The default HEC-RAS values were used in all simulations. Expansion and contraction coefficients were set to the default of 0.3 and 0.1 respectively.

4.4.12 The nature of the river reach has resulted in significant variation in cross sections leading to warnings regarding the large change in conveyance between upstream and downstream cross sections.

Baseline model results

4.4.13 The baseline model was run for the 50%, 20%, 10%, 5%, 2%, 1% and 0.1% flows. The estimate flood levels and flood extents are shown in Table 18 and Figure 12 below.

Figure 12: Baseline model extents

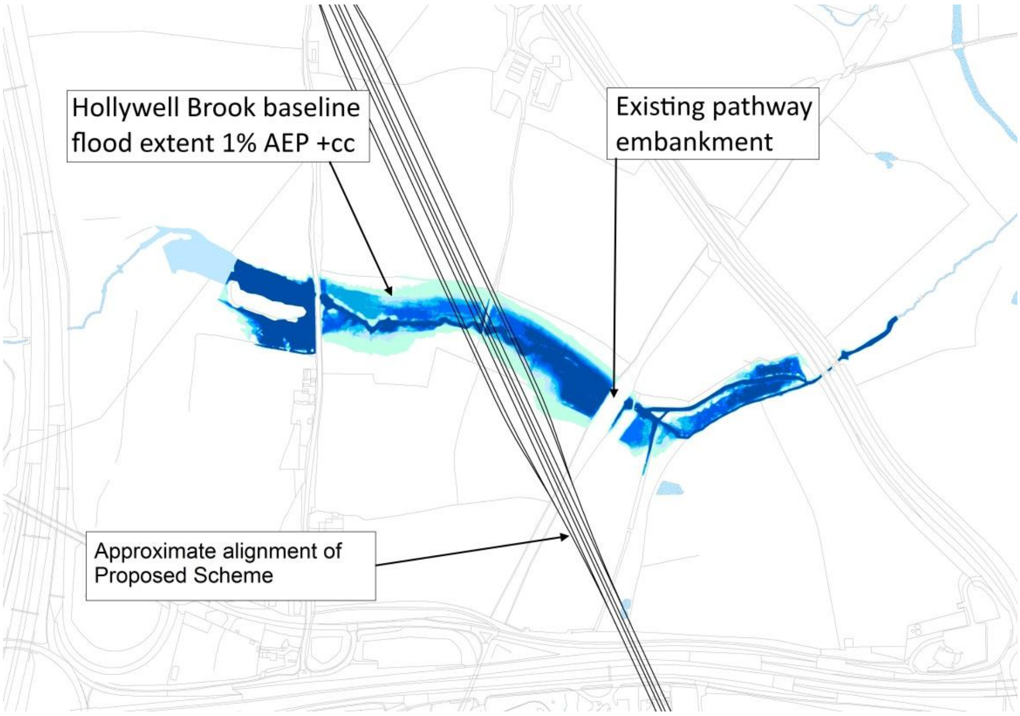


Table 18: Baseline model results

AEP	Estimated level upstream of the existing A452 Chester Road crossing – XS7	Estimated level upstream of Hollywell Brook underbridge– XS17
50%	83.761	85.893
20%	83.859	85.952
1%	83.933	85.989
5%	84.001	86.021
2%	84.096	86.064
1%	84.182	86.092
1% AEP + 20%	84.288	86.137
0.1%	84.551	86.485

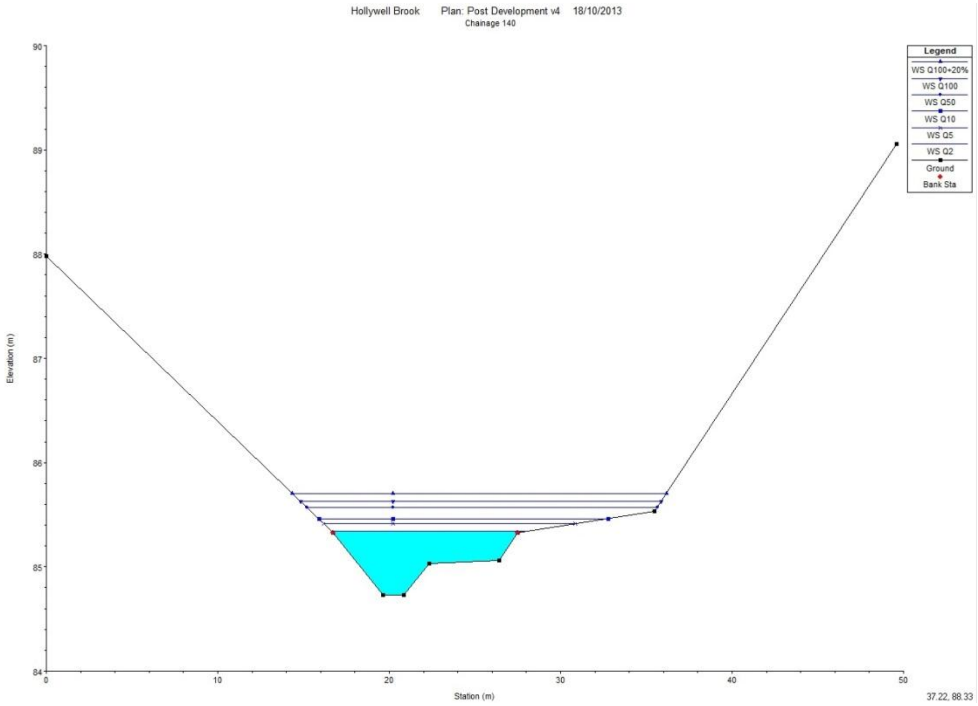
4.5 Post-development model

Overview

4.5.1 The post development model includes a new 4.5m span culvert beneath the A452 Chester Road diversion, a new 10m span bridge crossing beneath the Proposed Scheme and a diversion of the channel to provide a perpendicular crossing and minimise the length of watercourse that is culverted. A typical channel diversion cross section is shown in Figure 13.

4.5.2 Downstream of the Hollywell Brook underbridge there is an abandoned railway culvert (represented as a culvert at Bridge unit 10.5) which has been removed in the post development model and replaced with a bridge culvert with 1 in 4 side slopes to represent the extents of the earthworks remaining from the culvert removal.

Figure 13: Typical diversion cross section



Post development model results

4.5.3 The post development model was run for the same flow and boundary condition events as the baseline model.

4.5.4 The proposed model results and the change in peak water levels are shown in Table 19 and Table 20. Upstream of the Proposed Scheme changes to peak levels are up to 60mm, due to the removal of the railway embankment. Immediately upstream of the railway embankment the levels reduce by up to 470mm.

4.5.5 Upstream of the new A452 Chester Road culvert there is an estimated decrease in flood levels by up to 180mm. The decrease in flood level is caused by new culvert being positioned further downstream of the existing culvert at a lower elevation. A further model run will be undertaken to assess the pass forward flow using an unsteady state model run.

Table 19: Post development model results – A452Chester Road crossing (XS7)

AEP	Baseline - estimated level upstream of proposed A452 crossing, mAOD	Post development estimated level upstream of A452 Chester Road crossing, mAOD	Maximum estimated change in peak water level, m
50%	83.761	83.700	-0.061
20%	83.859	83.760	-0.099
10%	83.933	83.808	-0.125
5%	84.001	83.860	-0.141
2%	84.096	83.938	-0.158

AEP	Baseline - estimated level upstream of proposed A452 crossing, mAOD	Post development estimated level upstream of A452 Chester Road crossing, mAOD	Maximum estimated change in peak water level, m
1%	84.182	84.010	-0.172
1% AEP + 20%	84.288	84.106	-0.182
0.1%	84.551	84.378	-0.173

Table 20: Post development model results – Hollywell Brook underbridge (XS17)

AEP	Baseline - estimated level upstream of Hollywell Brook underbridge, mAOD	Post development estimated level upstream of Hollywell Brook underbridge, mAOD	Maximum estimated change in peak water level, m
50%	85.893	85.833	-0.06
20%	85.952	85.892	-0.06
10%	85.989	85.93	-0.059
5%	86.021	85.966	-0.055
2%	86.064	86.011	-0.053
1%	86.092	86.047	-0.045
1% AEP + 20%	86.137	86.091	-0.046
0.1%	86.485	86.193	-0.292

4.6 Sensitivity testing

Overview

4.6.1 Given the absence of calibration data, surveyed levels of flooding or historic flood outlines for the modelled reach of the Hollywell Brook, a range of sensitivity tests were undertaken for the most critical assumptions made during the model build. These are:

- roughness coefficients (sensitivity test 1);
- downstream boundary condition (sensitivity test 2); and
- blockage of proposed and existing structure (sensitivity test 3).

4.6.2 Sensitivity tests 1 & 2 were carried out for the 1% AEP plus climate change event, while sensitivity test 3 was undertaken for the 0.1% AEP event and will also be used to provide design 0.1% AEP flood level for the Proposed Scheme. Results are presented in the following sections.

Roughness coefficients (sensitivity test 1)

4.6.3 The post development model's sensitivity to roughness coefficients was assessed by considering ±20% variations on the adopted Manning's 'n' values.

Table 21: Post development model results

Sensitivity test	Flood level (upstream of Proposed Scheme (1% AEP + cc) – XS17, mAOD
Modelled roughness values -20%	86.044
Modelled roughness values	86.091
Modelled roughness values +20%	86.137

4.6.4 With a 20% increase to Manning's 'n' values the estimate flood level shows an increase of 46mm.

4.6.5 With a 20% decrease to Manning's 'n' values the estimate flood level shows a decrease of 47mm.

4.6.6 Manning's roughness values will remain at the default chosen values as they are considered to be at the higher range of recommended roughness values for river reach.

Downstream boundary condition (sensitivity test 2)

4.6.7 The baseline model's sensitivity to the downstream boundary condition was assessed by considering variation in downstream boundary condition by ± 0.5m on the adopted 1% AEP boundary level.

Table 22: Downstream boundary condition – baseline

Downstream boundary level, mAOD	Flood level (upstream of A452 crossing (1% AEP + cc), mAOD	Flood level (upstream of Proposed Scheme alignment (1% AEP + cc), mAOD
81.911	84.288	86.137
82.411	84.288	86.137
82.911	84.288	86.137

4.6.8 Varying the downstream boundary level by ± 0.5m does not alter the flood levels at the upstream side of the A452 Chester Road or the Proposed Scheme. The confluence with the Blythe is sufficiently far downstream so as not to influence the water levels at either location.

Structure blockage (sensitivity test 3)

4.6.9 Blockage analysis has been performed to determine the risk to the Proposed Scheme during extreme flood events (0.1% AEP). Blockages have been applied to existing culverts and the proposed route as follows:

- 10% blockage to the existing culvert module by setting a blockage depth equal to 10% of flow depth or raising bed level equal to 10% flow depth; and
- 2% or 10% blockage depth as appropriate to the bridge / viaduct structure by raising internal bridge cross sections by a level equal to 2% of depth at the cross section and increasing the pier width by 2% of the flow top width.

4.6.10 The Hollywell Brook underbridge (10m span) and A452 Chester Road (4m span culvert) crossings have been treated as culvert with 10% blockage as a conservative estimate.

4.6.11 As the model runs are steady state, consecutive structures have been blocked.

Table 23: Blockage analysis

Model	Flood level (upstream of Hollywell Brook underbridge (0.1%A EP) – XS15, mAOD	Flood level (upstream of Proposed Scheme (0.1% AEP) – XS23, mAOD
Post development model	85.863	87.218
Blockage analysis	85.896	87.218

4.6.12 Introducing a blockage to the Proposed Scheme bridges results in a minor increase (33mm) in the upstream flood level.

4.6.13 It should be noted that if the downstream railway embankment is retained the risk of blockage increasing the 0.1% AEP flood level is significant due to the relatively small size of the existing railway embankment culvert.

4.7 Uncertainty

4.7.1 Flood levels upstream of the Proposed Scheme will be used to inform the design levels. An uncertainty factor will be applied to these levels, calculated using the fluvial freeboard guidance note, R&D technical report W187 published by the Environment Agency.

4.7.2 The levels used are from the first cross section upstream of the Hollywell Brook underbridge and not the cross section used to report the baseline and post development model differences.

Table 24: Proposed Scheme design flood levels – cross section 15

Flood flow	Modelled level, mAOD	Uncertainty allowance, m	Design flood level, mAOD
1% AEP + 20%	85.675	0.135	85.810
0.1% AEP (including blockage analysis)	85.896	0.216	86.652

4.8 Model summary tables

Table 25: Baseline model results table

Baseline Levels, mAOD								
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**	**0.1% AEP**
20.0	86.725	86.757	86.778	86.789	86.815	86.826	86.856	86.919
19.0	86.725	86.757	86.778	86.790	86.815	86.827	86.856	86.917
18.5	86.724	86.757	86.777	86.788	86.813	86.825	86.853	86.910
18.0	86.009	86.078	86.122	86.157	86.198	86.229	86.273	86.500
17.0	85.893	85.952	85.989	86.021	86.064	86.092	86.137	86.485
16.0	85.717	85.777	85.813	85.844	85.885	85.917	85.979	86.472
15.0	85.562	85.634	85.672	85.698	85.727	85.776	85.898	86.464
14.0	85.247	85.338	85.393	85.450	85.554	85.667	85.848	86.456
13.0	85.097	85.195	85.275	85.364	85.505	85.638	85.833	86.453
12.0	85.003	85.132	85.230	85.333	85.486	85.625	85.825	86.450
11.0	84.974	85.066	85.175	85.284	85.444	85.588	85.791	86.422
10.0	84.661	84.719	84.763	84.802	84.854	84.896	84.956	85.094
9.0	84.091	84.165	84.216	84.265	84.328	84.381	84.455	84.659
8.0	83.912	83.968	84.019	84.069	84.147	84.223	84.319	84.570
7.0	83.761	83.859	83.933	84.001	84.096	84.182	84.288	84.551
6.0	83.008	83.087	83.131	83.180	83.243	83.296	83.366	83.551
5.0	82.708	82.775	82.822	82.869	82.934	82.992	83.069	83.281
4.0	82.476	82.557	82.607	82.660	82.735	82.795	82.882	83.129
3.0	82.035	82.144	82.287	82.359	82.454	82.427	82.385	82.342
2.0	81.694	81.793	81.551	81.566	81.577	81.934	82.411	82.410
1.0	81.160	81.219	81.352	81.371	81.397	81.973	82.411	82.411

Table 26: Post development model results table

Post development levels, mAOD								
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**	**0.1% AEP**
20	86.731	86.748	86.772	86.788	86.811	86.841	86.852	86.912
19	86.731	86.748	86.772	86.788	86.811	86.841	86.852	86.91
18.5	86.731	86.747	86.771	86.787	86.809	86.839	86.849	86.903
18	85.988	86.064	86.114	86.157	86.206	86.237	86.273	86.371
17	85.833	85.892	85.93	85.966	86.011	86.047	86.091	86.193
16.5	85.628	85.686	85.724	85.76	85.809	85.85	85.904	86.035
16	85.499	85.56	85.601	85.643	85.699	85.748	85.814	85.981
15.5	85.343	85.414	85.462	85.509	85.572	85.63	85.705	85.89
15	85.306	85.379	85.428	85.475	85.54	85.599	85.675	85.863
14.5	85.226	85.302	85.352	85.402	85.469	85.526	85.6	85.779
14	85.105	85.179	85.227	85.276	85.34	85.394	85.465	85.636
13	85.019	85.092	85.141	85.188	85.249	85.302	85.37	85.535
12	84.991	85.066	85.116	85.163	85.227	85.281	85.351	85.52
11	84.964	85.04	85.091	85.139	85.202	85.257	85.327	85.496
10	84.666	84.726	84.767	84.802	84.853	84.886	84.931	85.05
9	84.093	84.169	84.217	84.263	84.323	84.37	84.428	84.585
8	83.917	83.973	84.007	84.039	84.086	84.13	84.198	84.423
7	83.7	83.76	83.808	83.86	83.938	84.01	84.106	84.378
6	83.565	83.661	83.731	83.797	83.89	83.97	84.075	84.36
5	82.708	82.774	82.822	82.869	82.935	82.991	83.068	83.277
4	82.476	82.557	82.607	82.66	82.735	82.795	82.882	83.129
3	82.035	82.144	82.287	82.359	82.454	82.427	82.385	82.342
2	81.694	81.793	81.551	81.566	81.577	81.934	82.411	82.41
1	81.157	81.218	81.352	81.371	81.397	81.973	82.411	82.411

Table 27: Baseline and post development model results comparison

Comparison, m								
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**	**0.1% AEP**
20	0.01	-0.01	-0.01	0.00	0.00	0.02	0.00	-0.01
19	0.01	-0.01	-0.01	0.00	0.00	0.01	0.00	-0.01
18.5	0.01	-0.01	-0.01	0.00	0.00	0.01	0.00	-0.01
18	-0.02	-0.01	-0.01	0.00	0.01	0.01	0.00	-0.13
17	-0.06	-0.06	-0.06	-0.06	-0.05	-0.05	-0.05	-0.29
16.5	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
15.5	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-
14.5	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
12	-0.01	-0.07	-0.11	-0.17	-0.26	-0.34	-0.47	-0.93
11	0.01	-0.03	-0.08	-0.15	-0.24	-0.33	-0.46	-0.93
10	0.00	0.01	0.00	0.00	0.00	-0.01	-0.03	-0.04
9	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.03	-0.07
8	0.00	0.00	-0.01	-0.03	-0.06	-0.09	-0.12	-0.15
7	-0.06	-0.10	-0.13	-0.14	-0.16	-0.17	-0.18	-0.17
6	-	-	-	-	-	-	-	-
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

5 Lavender Hall Lane Model

5.1 Introduction

5.1.1 The hydraulic models cover a localised reach of the Bayleys Brook, a tributary of the River Blythe. The section of watercourse modelled extends from grid reference 424234, 278245 upstream to grid reference 424043, 278591 downstream; a total reach length of 0.53km around the proposed structure and a predominantly rural catchment area of 6.53km².

5.1.2 The Proposed Scheme requires the diversion of and vertical realignment of Lavender Hall Lane, which will require a new crossing of the Bayleys Brook. However, at the Bayleys Brook crossing point the existing Lavender Hall Lane will be retained to allow continued access to adjacent agricultural land and Park Lane. This will mean the existing culverts will remain in place.

5.2 Hydrology

Derivation of inflows

5.2.1 A preliminary hydrological investigation has been undertaken in order to understand the magnitude of flows generated by the catchment up to a point a short distance downstream the proposed crossing point of the Proposed Scheme. This has been done using the revitalised rainfall runoff methodology. The calculated flows are shown in Table 28. Full details of the calculation process can be found in Volume 5: Appendix WR-004-016.

Table 28: Flow calculation results using ReFH

Annual exceedence probability (AEP)	Flow (m^3/s)
50%	1.8
20%	2.4
10%	2.8
5%	3.2
2%	3.9
1.33%	4.3
1%	4.6
1% AEP + 20%	5.5
1% AEP + 30%	5.9
0.1%	8.1

5.3 Hydraulic models

Overview

5.3.1 1D steady state model (HEC-RAS) has been used to represent the main channels and rural floodplains of the Bayleys Brook for the pre- and post-development scenarios and a range of storm events with AEPs of 50%, 20%, 10%, 5%, 2%, 1.33%, 1%, and 0.1%. In addition the model has been used to simulate the performance during the 1% AEP flood event plus an additional 30% added to the flow to allow for changes due to climate change.

5.3.2 A 1D steady state model was considered appropriate for this river reach due to the relatively uniform, narrow floodplain. This choice of model allows the representation of the main features present in the area of interest and the estimation of their effects on extreme water levels. The main features in the modelled extent are:

- water levels and conveyance along the Bayleys Brook, taking into account the channels' geometry and roughness;
- water levels and conveyance across the river's floodplains, taking into account ground levels, land uses and obstructions to flow (e.g. road embankments, buildings, etc.); and
- impact on water levels and flood flow conveyance of the proposed Lavender Hall Lane diversion and the new crossing required by this activity (refer to Section 5.5).

5.4 Baseline model

5.4.1 To aid navigation of the model files the key baseline files are described in Table 29 in terms of file type, file title and name.

Table 29: Baseline model files

File type	File title	File name
Project (.prj)	Lavender Hall Lane	LavenderHallLane.prj
.gXX	Existing Layout	LavenderHallLane.g01
.fXX	ReFH Hydrology	LavenderHallLane.f01
.pXX	Existing Layout + ReFH	LavenderHallLane.p01

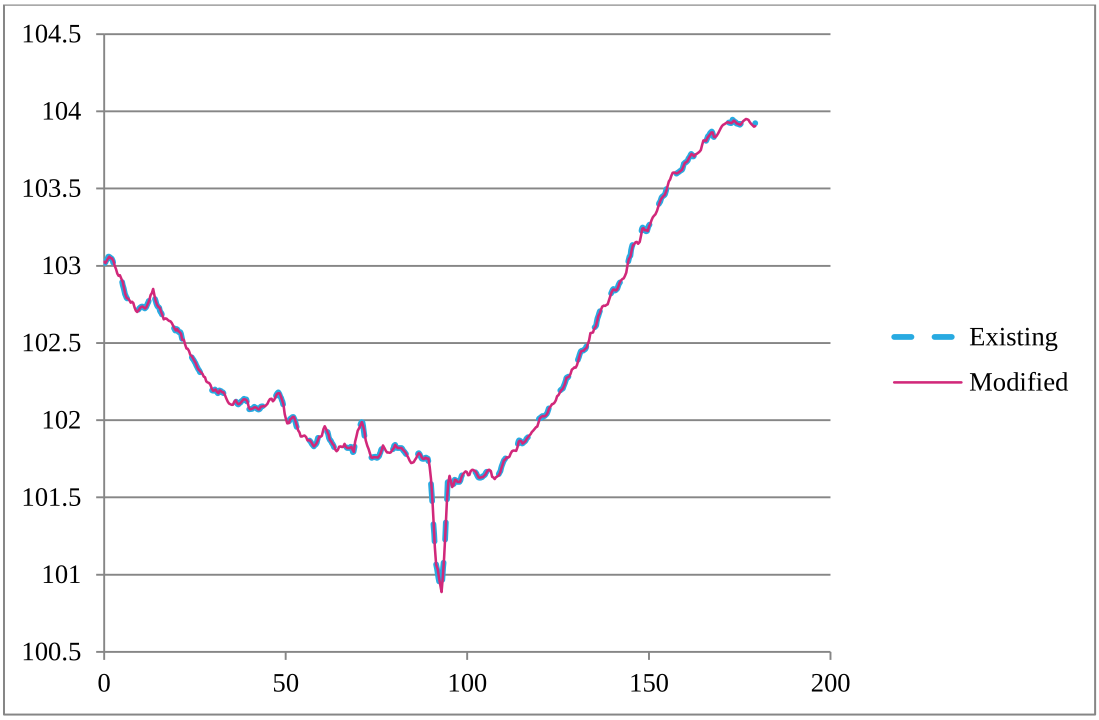
Topography

5.4.2 LiDAR data (refer to Section 2.2) was used to obtain ground levels across the reach extent. Cross sections were derived from LiDAR data inserted into ArcGIS as a raster image and the number of points in each cross section adjusted to comply with HEC-RAS's 500 station maximum limit.

5.4.3 Road deck information was also obtained using the same method.

5.4.4 The reduction in station points has been achieved without losing definition of either the floodplains or channel. This was possible due to the relatively short cross section lengths and the high resolution of the LiDAR data, enabling station points to be removed without altering the geometric shape of floodplain or channel. A typical representation of the cross sections showing the before and after scenarios are included below for information.

Figure 14: Typical cross section showing reduced station data



5.4.5 All field boundaries are assumed to enable conveyance of flood flows.

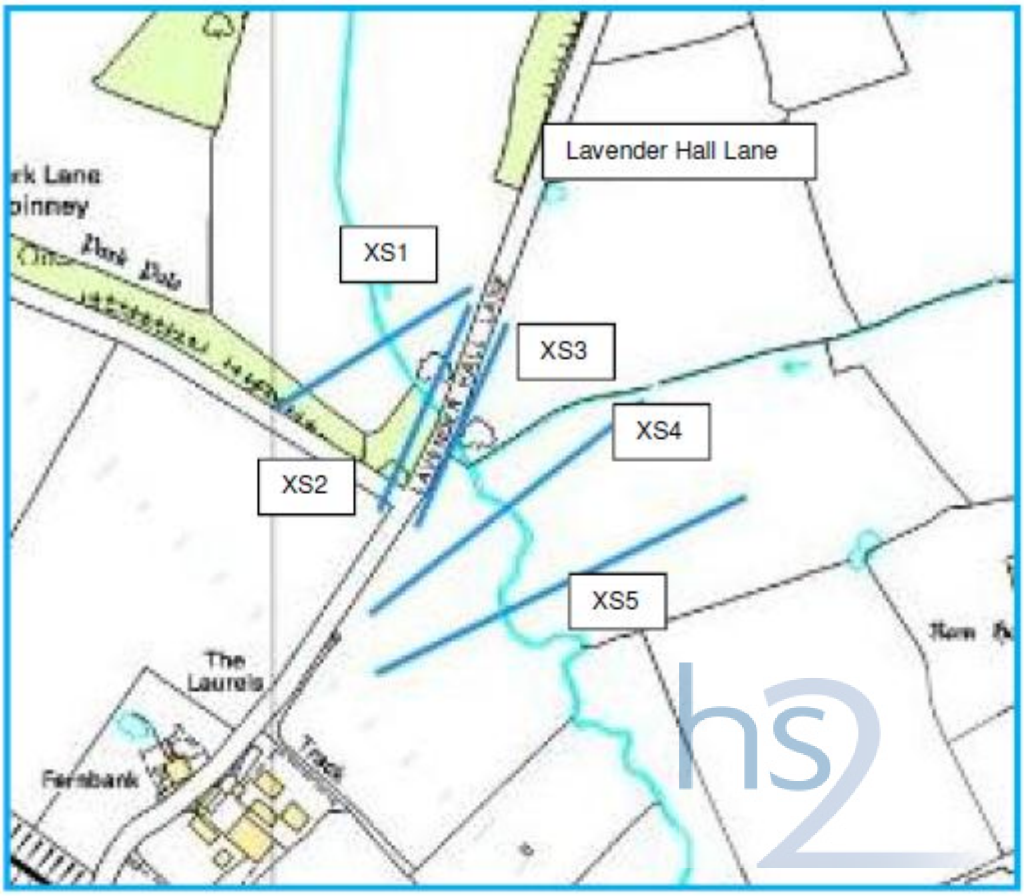
Cross section location

5.4.6 Cross section locations were selected in relation to obstructions to be modelled. In this case the key feature is the existing and proposed Lavender Hall Lane crossing.

5.4.7 A bridge has been placed in the baseline model at a cross section between cross section 3 and cross section 4. This represents the location of the proposed structure. The structure in the baseline model is a 'dummy' deck set at a level which will not impact water levels. There are no piers or abutments associated with this deck. It has been inserted into the model at the baseline stage as the water levels generated by some models can be affected by simply inputting a structure, even if the structure does not affect the hydraulic performance of the system. It would appear that inserting this structure has increased upstream baseline water levels by between 6mm and 1mm.

5.4.8 The cross sections locations are shown in Figure 15.

Figure 15: Cross-section locations used in Lavender Hall Lane river hydraulic model



Land use and roughness coefficients

5.4.9 Roughness coefficients were specified as Manning's 'n' values. Site observations were not possible for much of the reach and so global roughness values were applied. Ordnance Survey MasterMap data and aerial photography was used to establish land uses and manning roughness values applied to suit.

Ineffective flow areas

5.4.10 Ineffective flow areas were applied upstream and downstream of the existing and proposed structure as appropriate.

Downstream boundary conditions

5.4.11 The boundary of the model extends for approximately 100m downstream of the existing Lavender Hall Road. There are no downstream hydraulic features or additional inflows which could influence water levels. Therefore, the proposed baseline model assumes a 'normal depth' level-flow relationship as a downstream boundary condition for all return period flows modelled, using a slope of 0.00588. This slope has been calculated based on distance and level measurements taken from the LiDAR data using GIS.

Runtime parameters and model performance

5.4.12 The default HEC-RAS values were used in all simulations. Expansion and contraction coefficients were set to the default of 0.3 and 0.1 respectively.

5.4.13 The model has generated the following warnings throughout the model:

- divided flow computed for this cross section;
- the conveyance ratio (upstream conveyance divided by downstream conveyance) is less than 0.7 or greater than 1.4. This may indicate the need for additional cross sections;
- the energy loss was greater than 0.3m between the current and previous cross sections. This may indicate the need for additional cross sections; and
- multiple critical depths were found at this location. The critical depth with the lowest, valid, energy was used.

5.4.14 The baseline model was run for the 50%, 20%, 10%, 5%, 2%, 1.33%, 1%, 1% + cc and 0.1% AEP flows. The estimated flood levels for cross section 4 (XS4) (located approximately 109m upstream of the existing crossing point) are shown in Table 30. This cross section has been chosen as it will remain unaffected by the proposed Lavender Hall Lane diversion, while cross section 3 will be significantly altered by the proposed works.

Table 30: Baseline model results (XS4)

Annual exceedence probability (AEP)	Estimated level upstream of Proposed Scheme crossing
50%	102.05
20%	102.126
10%	102.198
5%	102.302
2%	102.405
1.33%	102.409
1%	102.412
1% AEP + 30%	102.448
0.1%	102.516

5.5 Post-development model

5.5.1 To aid navigation of the model files the key post development files are described in Table 31 in terms of file type, file title and name.

Table 31: Post development model files

File type	File Title	File Name
Project (.prj)	Lavender Hall Lane	LavenderHallLane.prj
.gXX	Multiple Openings	LavenderHallLane.g02
.fXX	ReFH Hydrology	LavenderHallLane.f01
.pXX	Multi culvert options	LavenderHallLane.p04

Post-development model results

5.5.2 The post-development model was run using the same flow and boundary conditions as the baseline model. The flow data is LavenderHallLane.f01.

5.5.3 The proposed model results are shown in Table 32 and Table 33.

Table 32: Post development model results (XS4)

AEP	Baseline water level, mAOD	Post development water level, mAOD	Maximum estimated change in peak water level, m
50%	102.05	102.044	-0.006
20%	102.126	102.137	0.011
10%	102.198	102.212	0.014
5%	102.302	102.315	0.013
2%	102.405	102.422	0.017
1.33%	102.409	102.428	0.019
1%	102.412	102.434	0.022
1% AEP + 30%	102.448	102.467	0.019
0.1%	102.516	102.558	0.042

Table 33: Post development model results (XS5)

AEP	Baseline water level, mAOD	Post development water level, mAOD	Maximum estimated change in peak water level, m
50%	102.445	102.451	0.006
20%	102.478	102.477	-0.001
10%	102.481	102.487	0.006
5%	102.479	102.501	0.022
2%	102.517	102.552	0.035
1.33%	102.537	102.572	0.035
1%	102.55	102.585	0.035
1% AEP + 30%	102.603	102.641	0.038
0.1%	102.679	102.727	0.048

5.5.4 In terms of changes to peak flows, results show that upstream increases are negligible being no greater than 0.038 at XS5 for the 1% AEP plus cc event. The changes exceed reach 0.048m for the 0.1% AEP at XS5. This amount of variation is considered acceptable.

5.5.5 In order to improve the reliability of the proposed model additional cross sections were inserted between the upstream cross section (XS4) and the proposed culvert. This reduced the transition between the two cross sections. This was necessary as the model indicated critical depth at the entrance to the culvert for the 50% AEP flood event. By introducing additional cross with adjusted channel dimensions the impact of this anomaly was reduced.

5.6 Sensitivity testing

Overview

5.6.1 Given the absence of calibration data or surveyed levels of historic flood outlines for the Bayleys Brook, a range of sensitivity tests were undertaken for the most critical assumptions made during the model build. These are:

- roughness coefficients (sensitivity test 1);
- downstream boundary condition (sensitivity test2); and
- blockage of proposed and existing structure (sensitivity test 3).

5.6.2 Sensitivity test 1 was carried out for the 1% AEP plus cc event, test 2 for the full range of flows and sensitivity test 3 was undertaken for the 0.1% AEP event and will also be used to provide design 0.1% AEP flood level for the Proposed Scheme. Results are presented in the following sections.

Roughness coefficients (sensitivity test 1)

5.6.3 The baseline model's sensitivity to roughness coefficients was assessed by considering ±20% variations on the adopted Manning's 'n' values.

Table 34: Sensitivity test – roughness values

Sensitivity test	**1% AEP plus cc flood level (XS4), mAOD**
Modelled roughness values -20%	102.458
Modelled roughness values	102.448
Modelled roughness values +20%	102.441

5.6.4 With a 20% increase to Manning's 'n' values (floodplain from 0.085 to 0.102, main channels 0.055 to 0.066 and structure 0.015 to 0.018) the flood levels show a maximum increase of 0.089m at XS4 for the 10% AEP event. Generally a change of approximately 0.03m was observed at XS4 and XS5.

5.6.5 With a 20% decrease to Manning's 'n' values (floodplain from 0.085 to 0.068, main channel 0.055 to 0.044 and structure 0.015 to 0.012) the estimated flood levels shows a decrease of approximately 0.03m.

Downstream boundary condition (sensitivity test 2)

5.6.6 The downstream boundary has been changed considering three different fixed water levels and three different downstream slope profiles in order to set normal depth. The results for the 1% AEP plus cc event are shown in Table 35.

Table 35: Sensitivity testing - downstream boundary

Downstream boundary	Water level (m AOD) at XS3	Relative change, m	Water level (m AOD) at XS4	Relative change, m
Normal depth S = 0.0058	102.418	Baseline	102.448	Baseline
102.00	1021.416	-0.002	102.447	-0.001
102.50	102.519	0.101	102.536	0.088
103.00	103.015	0.597	103.017	0.596
Normal depth S = 0.01	102.424	0.006	102.453	0.005
Normal depth S = 0.001	102.413	-0.005	102.444	-0.004
Normal depth S = 0.0001	102.427	0.009	102.455	0.007

5.6.7 This indicates that the model is sensitive to changes in downstream boundary conditions in terms of a fixed downstream water level with a downstream water level of 103m generating a change in excess of 0.5m up and downstream of the proposed culvert location.

5.6.8 In addition the slope used in the normal depth calculation has also been varied from 0.00588 to i) 0.01, ii) 0.001 and iii) 0.0001. These variations have generated water levels of less than 0.01 m up and downstream of the proposed culvert location.

Structure blockage (sensitivity test 4)

5.6.9 Blockage analysis has been performed to determine the risk to the Proposed Scheme during extreme flood events (0.1% AEP). Blockages have been applied to existing culverts and the proposed route using a10% blockage to the existing and proposed culvert module by setting a blockage depth equal to 10% of flow depth

Table 36: Sensitivity testing - blockage

Model	Flood level (upstream of Proposed Scheme (0.1% AEP), mAOD
Post development model	102.516
Blockage analysis	102.603

5.6.10 Introducing a blockage to the Proposed Scheme results in 0.087m change to the estimated flood level at XS4.

5.7 Uncertainty

5.7.1 Flood levels upstream of the Proposed Scheme will be used to inform the design levels. An uncertainty factor will be applied to these levels, calculated using the fluvial freeboard guidance note, R&D technical report W187 published by the Environment Agency.

Table 37: Proposed Scheme design flood levels

Flood flow	Modelled level, mAOD	Uncertainty allowance, m	Design flood level, mAOD
1% AEP + 30%	102.467	0.13	102.597
0.1% AEP (including blockage analysis)	102.603	0.17	102.773

5.8 Model results tables

Table 38: Baseline model results

Baseline									
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	1% AEP + cc	0.1% AEP
5.0	102.445	102.478	102.481	102.479	102.517	102.537	102.55	102.603	102.679
4.0	102.05	102.126	102.198	102.302	102.405	102.409	102.412	102.448	102.516
3.0	101.861	102.022	102.145	102.277	102.389	102.389	102.389	102.418	102.477
2.0	101.724	101.794	101.831	101.866	101.917	101.944	101.963	102.033	102.126
1.0	101.463	101.507	101.527	101.546	101.574	101.589	101.601	101.64	101.695

Table 39: Post development model results

Post-development									
	50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1.33% AEP	1% AEP	1% AEP + cc	0.1% AEP
5.0	102.451	102.477	102.487	102.501	102.552	102.572	102.585	102.641	102.727
4.0	102.044	102.137	102.212	102.315	102.422	102.428	102.434	102.467	102.558
3.0	101.857	102.017	102.141	102.273	102.385	102.384	102.383	102.395	102.454
2.0	101.724	101.794	101.831	101.866	101.917	101.944	101.963	102.033	102.126
1.0	101.463	101.507	101.527	101.546	101.574	101.589	101.601	101.64	101.695

Table 40: Baseline and post development comparison

Comparison									
	50% AEP	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1.33% AEP**	**1% AEP**	**1% AEP + cc**	**0.1% AEP**
5.0	0.006	-0.001	0.006	0.022	0.035	0.035	0.035	0.038	0.048
4.0	-0.006	0.011	0.014	0.013	0.017	0.019	0.022	0.019	0.042
3.0	-0.004	-0.005	-0.004	-0.004	-0.004	-0.005	-0.006	-0.023	-0.023
2.0	0	0	0	0	0	0	0	0	0
1.0	0	0	0	0	0	0	0	0	0

6 Marsh Farm viaduct

6.1 Introduction

6.1.1 The hydraulic models cover a localised reach of the Bayleys Brook which is an ordinary watercourse main river and tributary of the River Blythe. The section of watercourse modelled extends from grid reference 422702, 279796 upstream to grid reference 421666, 280362 upstream of the confluence with the River Blythe; a total reach length of 1.54km around the proposed structures and a semi-rural catchment area of 11.3km^2.

6.1.2 The Proposed Scheme interacts with the Bayleys Brook between chainages 152+500 and 152+700 and incorporates the A452 Kenilworth Road diversion and bridleway (ref: M218).

6.2 Model limitations and further development

6.2.1 Further iterations of this model would benefit from a two dimensional modelling approach due to the predicted separation between channel and floodplain on the downstream side of the Proposed Scheme. The model is considered sufficiently accurate to assess the impact of the Proposed Scheme at this stage of the project.

6.3 Hydrology

Derivation of inflows

6.3.1 A preliminary hydrological investigation has been undertaken in order to understand the magnitude of flows generated by the catchment up to a point a short distance downstream the proposed crossing point of the Proposed Scheme.

6.3.2 The catchment is semi-rural with small urban contributions from Balsall Common and Berkswell. The flows generated by the ReFH spreadsheet are shown in Table 41 below.

Table 41: Peak flow calculation results using ReFH

Annual exceedence probability (AEP)	Flow (m^3/s)
50%	2.27
20%	2.94
10%	3.46
5%	3.99
2%	4.82
1.33%	5.24
1%	5.56
1% AEP + 20%	6.67
1% AEP + 30%	7.23
0.1%	9.73

6.4 Hydraulic models

Overview

6.4.1 A 1D steady state model (HEC-RAS) was used to represent the watercourse main channel and rural floodplains for the pre- and post-development scenarios and a range of storm events with annual exceedence probabilities of 50%, 20%, 10%, 5%, 2%, 1% and 0.1%.

6.4.2 A 1D steady state model was considered appropriate for this river reach due to the relatively uniform floodplain at the location of the Proposed Scheme. The choice of 1D model does have some limitations related to the shallow, depressed floodplains and a sensitivity test involving the use of levees has been applied in order to determine design flood levels to inform the flood risk assessment.

6.4.3 Furthermore detailed design of the crossing would benefit from a 2D modelling approach to more accurately assess the movement of water across the floodplain in relation to the channel position.

6.4.4 This choice of model allows the representation of the main features present in the area of interest and the estimation of their effects on extreme water levels. The main features in the modelled extent are:

- water levels and conveyance along Bayleys Brook, taking into account the channels' geometry and roughness;
- water levels and conveyance across the river's floodplains, taking into account ground levels, land uses and obstructions to flow (e.g. road embankments, buildings, etc.); and
- impact on water levels and flood flow conveyance of the Proposed Scheme infrastructure (refer to Section 6.6).

6.5 Baseline model

6.5.1 All models are located within the MarshFarmv2.prj file.

Table 42: Model files

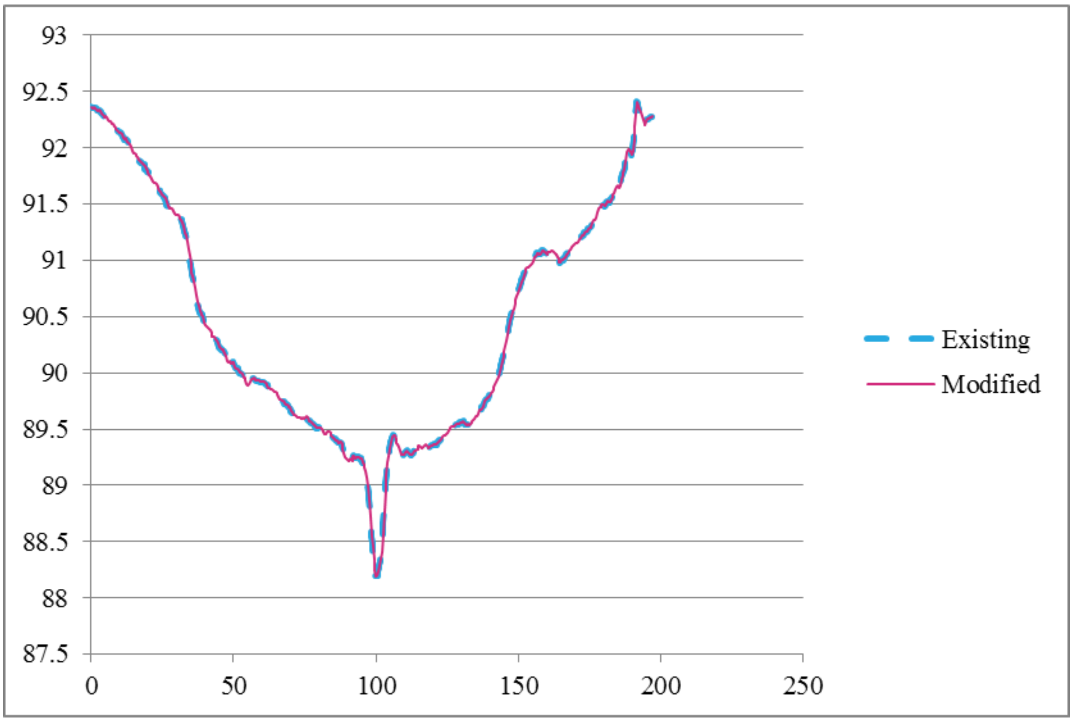
Model Title	Geometry File Title
Baseline	Baselinev5
Post Development Model	Post Development Modelv9

Topography

6.5.2 LiDAR data (refer to Section2.2) was used to obtain ground levels across the reach extent. Cross sections were derived from LiDAR data inserted into ArcGIS as a raster image and the number of points in each cross section adjusted to comply with HEC-RAS's 500 station maximum limits. Road deck information was also obtained using the same method.

6.5.3 The reduction in station points has been achieved without losing definition of either the floodplains or channel. This was possible due to the relatively short cross section lengths and the high resolution of the LiDAR data, enabling station points to be removed without altering the geometric shape of floodplain or channel. A typical representation of the cross sections showing the before and after scenarios are included below for information.

Figure 16: Typical cross section showing reduced station data



6.5.4 All field boundaries are assumed to enable conveyance of flood flows.

Cross section location

6.5.5 Cross section locations were selected in relation to obstructions to be modelled including an existing culvert and Marsh Farm viaduct. For the baseline model additional cross sections were inserted as highlighted in green with the bridge model represented between them but with a skew applied to the viaduct opening and piers to represent the skew angle of the crossing. Cross sections locations are shown in Figure 17.

Figure 17: Cross section locations

Land use and roughness coefficients

6.5.6 Roughness coefficients were specified as Manning's 'n' values. Site observations were not possible for much of the reach and global roughness values were applies. Ordnance Survey MasterMap data and aerial photography was used to establish land uses and manning roughness values applied to suit.

Ineffective flow areas

6.5.7 Ineffective flow areas were applied at the following locations:

- on the upstream and downstream side of culverts and bridges to represent areas not conveying flow due to upstream or downstream restrictions; and
- to cross sections 10.5, 10, 9 and 8.2, 8.3 and 8.4 to reflect the skew angle of the structure across the floodplain and the resultant restriction in flow caused by the embankments.

Downstream boundary condition

6.5.8 The proposed baseline model assumes a 'normal depth' level-flow relationship as a downstream boundary condition for flows from 50% to 2% AEPs. For the 1% and 0.1% AEP flows the boundary condition is set to the River Blythe flood level interpreted from Environment Agency flood maps as per those given in Table 43.

Table 43: Boundary condition applied

AEP	Boundary condition
50%, 20%, 10%, 5%, 2%, 1%, 1% AEP + 20%	Normal depth
0.1%	Fixed water level = 88.50m AOD

6.5.9 There is a degree of uncertainty regarding the flood mapping at the downstream section of the modelled reach due to the conservative approach to the downstream boundary conditions, combined with uncertainty regarding the River Blythe flood levels. To improve the flood mapping near to the Blythe confluence it will be necessary to model the appropriate section of the River Blythe.

6.5.10 No joint probability analysis has been undertaken on the Blythe and Blythe Bypass crossing and the likelihood of combined extreme flood events is probably unlikely given the relative catchment sizes. The application of 0.1% AEP flood levels for the boundary condition is likely to be a conservative assessment. A sensitivity analysis has been undertaken on the boundary condition applied for the 1% AEP plus climate change flow to determine the sensitivity of inaccuracy in existing flood levels.

Runtime parameters and model performance

6.5.11 The default HEC-RAS values were used in all simulations. Expansion and contraction coefficients were set to the default of 0.3 and 0.1 respectively.

6.5.12 The nature of the river reach has resulted in significant variation in cross sections leading to warnings regarding the large change in conveyance between upstream and downstream cross sections.

Baseline model results

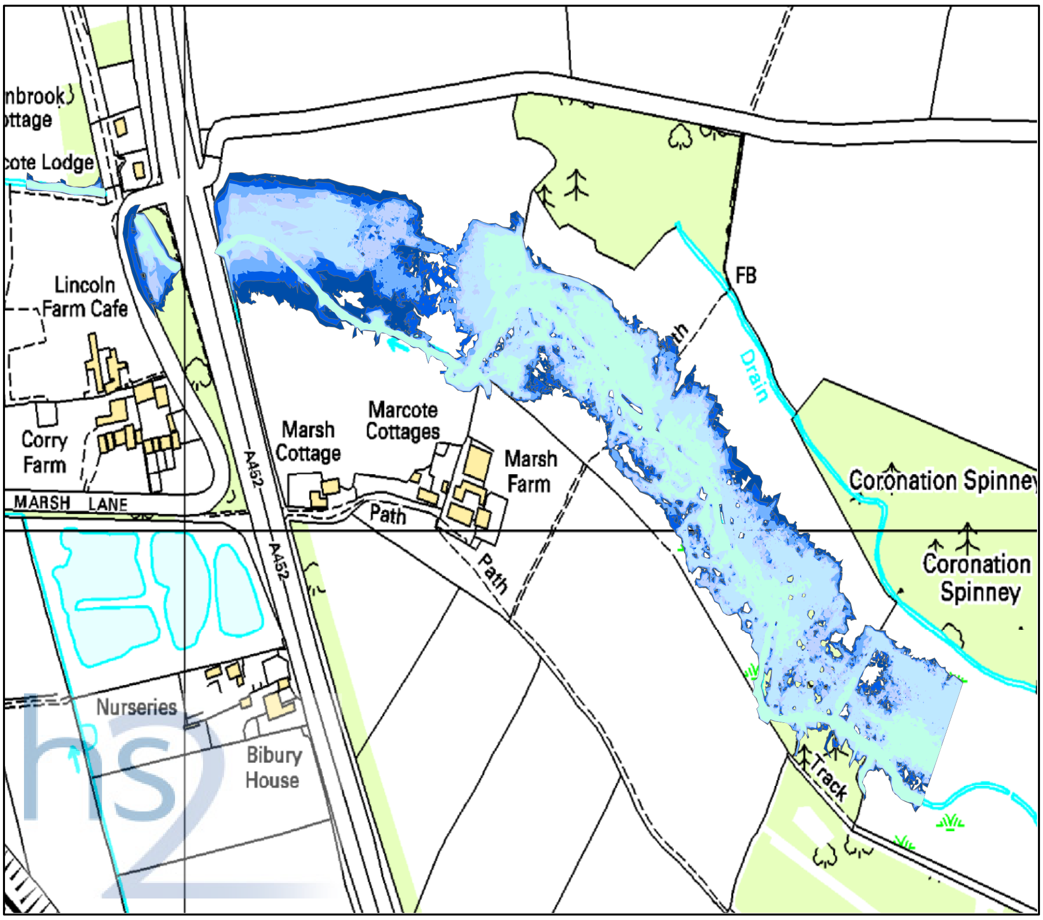
6.5.13 The baseline model was run for the 50%, 20%, 10%, 5%, 2%, 1% and 0.1% AEP flows. The estimate flood levels and flood extents are shown in Table 44 and Figure 18 below.

Table 44: Baseline model results

AEP	Estimated level upstream existing A452 Kenilworth Road crossing (XS 8), mAOD	Estimated level upstream of Marsh Farm viaduct (XS 8.4), mAOD	Estimated level 100m upstream of Marsh Farm viaduct (XS 11), mAOD
50%	89.436	90.343	90.769
20%	89.497	90.371	90.829
10%	89.551	90.393	90.867
5%	89.592	90.413	90.902
2%	89.697	90.435	90.944
1%	89.879	90.454	90.976
1% AEP + 20%	89.995	90.478	91.011

AEP	Estimated level upstream existing A452 Kenilworth Road crossing (XS 8), mAOD	Estimated level upstream of Marsh Farm viaduct (XS 8.4), mAOD	Estimated level 100m upstream of Marsh Farm viaduct (XS 11), mAOD
0.1%	90.308	90.582	91.094

Figure 18: Baseline model flood extents



6.6 Post-development model

Overview

6.6.1 The post development model includes a new 4.8m span culvert beneath the A452 Kenilworth Road diversion, a new 142m span viaduct crossing beneath the route with five 2m wide piers equally spaced.

Bridge modelling approach

6.6.2 The viaduct structure has been modelled by inserting the structure between the baseline model cross sections 8.3 and 8.4 which in reality would cut through the bridge structure.

6.6.3 The viaduct has been modelled with a reduced opening dimension and piers both skewed at 20 degrees to the flow angle. The actual viaduct cuts through the floodplain at 40 degrees but there is acknowledged to be a degree of change in direction of flow without impact on flood levels.

6.6.4 The relevant cross sections have been assigned with ineffective flow areas to represent embankment.

6.6.5 This approach to modelling the viaduct is preferable to the option of inserting cross sections on the upstream and downstream faces which tends to overestimate the channel capacity by incorporating downstream floodplain which is at much lower level than the channel, causing divided flow.

Post-development model results

6.6.6 The post-development model was run for the same flow and boundary condition events as the baseline model.

6.6.7 The hydraulics through the channel between the new A452 Kenilworth Road culvert and the Marsh Farm viaduct lead to a fluctuation in estimated water levels. The floodplain is wide with shallow water depth and divided flow between channel and floodplain predicted to occur.

6.6.8 A sensitivity analysis has also been performed which includes levees. This is included in Section 6.7.

6.6.9 The proposed model results and the changes in peak water levels are shown in Table 45 and Table 46. Upstream of the new A452 Kenilworth Road culvert there is an estimated decrease in flood levels for return period events up to the 1% AEP event due to the increased capacity within the replacement culvert. The 1% AEP plus climate change event demonstrates a negligible increase in estimated upstream water level.

6.6.10 Upstream of the A452 Kenilworth Road alignment changes to peak flows are predicted to decrease for all flows except the 1% AEP with climate change and 0.1% AEP events. The 1% AEP with climate change event shows a negligible increase of 15mm (<1% increase).

Table 45: Post development model results – A452 crossing

AEP	Baseline - estimated level upstream proposed A452 Kenilworth Road crossing (XS 8), mAOD	Post development estimated level upstream of A452 Kenilworth Road crossing(XS 8), mAOD	Maximum estimated change in peak water level, m
50%	89.605	89.443	-0.162
20%	89.672	89.498	-0.174
1%	89.704	89.551	-0.153
5%	89.707	89.609	-0.098
2%	89.741	89.735	-0.006
1%	89.843	89.849	0.006

AEP	Baseline - estimated level upstream proposed A452 Kenilworth Road crossing (XS 8), mAOD	Post development estimated level upstream of A452 Kenilworth Road crossing(XS 8), mAOD	Maximum estimated change in peak water level, m
1% AEP + 20%	90.028	90.028	0.000

6.6.11 Upstream of the Proposed Scheme the flood levels are predicted to increase by up to 49mm with a decrease by a similar amount at the next cross section located 68m upstream (results not included). This is representative of the fluctuation in levels as discussed above. At a distance of 100m upstream of the route crossing there is a negligible increase in flood levels (maximum 11mm up to and including the 1% AEP with climate change event).

Table 46: Post development model results – route crossing

AEP	Baseline - estimated level upstream of Marsh Farm viaduct, (XS 8.4), mAOD	Baseline - estimated level 100m upstream of Marsh Farm viaduct, (XS 11), mAOD	Post development estimated level upstream of Marsh Farm viaduct, (XS 8.4), mAOD	Post development - estimated level 100m upstream of Marsh Farm viaduct, (XS 11), mAOD	Maximum estimated change in peak water level U upstream of Marsh Farm viaduct, m	Maximum estimated change in peak water level 100m U/S Proposed Scheme crossing, m
50%	90.521	90.788	90.521	90.788	0.000	0.000
20%	90.594	90.842	90.59	90.842	-0.004	0.000
10%	90.645	90.875	90.642	90.875	-0.003	0.000
5%	90.676	90.903	90.673	90.903	-0.003	0.000
2%	90.71	90.938	90.712	90.938	0.002	0.000
1%	90.734	90.968	90.74	90.968	0.006	0.000
1% AEP+20%	90.77	90.997	90.776	90.998	0.006	0.001

6.7 Sensitivity testing

Overview

6.7.1 Given the absence of calibration data, surveyed levels of flooding or historic flood outlines for the modelled reach of the Bayleys Brook, a range of sensitivity tests were undertaken for the most critical assumptions made during the model build. These are:

- roughness coefficients (sensitivity test 1);
- downstream boundary condition (sensitivity test 2);
- blockage of proposed and existing structure (sensitivity test 3); and
- inclusion of levees (sensitivity test 4).

6.7.2 Sensitivity tests 1, 2 & 4 were carried out for the 1% AEP plus climate change) event, while sensitivity test 3 was undertaken for the 0.1% AEP event and will also be used to provide design 0.1% AEP flood level for the Proposed Scheme. Results are presented in the following sections.

Roughness coefficients (sensitivity test 1)

6.7.3 The post development model's sensitivity to roughness coefficients was assessed by considering ±20% variations on the adopted Manning's 'n' values.

Table 47: Post development model results

Sensitivity test	Flood level (100m upstream of Proposed Scheme (1% AEP + cc), mAOD
Modelled roughness values -20%	90.971
Modelled roughness values	90.998
Modelled roughness values +20%	91.030

6.7.4 With a 20% increase to Manning's 'n' values the estimate flood level shows an increase of only 32mm.

6.7.5 With a 20% decrease to Manning's 'n' values the estimate flood level shows a decrease of only 27mm.

6.7.6 Manning's roughness values will remain at the default chosen values as they are considered a reasonable approximation of roughness values within the catchment and tend on the conservative side for this model reach.

Downstream boundary condition (sensitivity test 2)

6.7.7 The baseline model's sensitivity to the downstream boundary condition was assessed by considering variation in downstream boundary condition by increasing the adopted 1% AEP boundary level and also comparing the normal depth boundary condition.

Table 48: Downstream boundary condition for 1% AEP +cc

Downstream boundary level, mAOD	Flood level (upstream of A452 Kenilworth Road crossing - 1% AEP + cc), mAOD	Flood level (upstream of Proposed Scheme - 1% AEP + cc), mAOD
Normal depth (DS level = 87.135)	90.028	90.776
88.000	90.028	90.776
88.500	90.028	90.776

6.7.8 The sensitivity analysis demonstrates that the flood levels are unaffected by the downstream boundary condition at the Marsh Farm viaduct. Increasing the level by over 1m does not alter the flood levels at the upstream side of the A452 Kenilworth Road or the Proposed Scheme predominantly because of the backwater effect caused by the existing Marsh Lane culvert. The normal depth boundary condition will be used for all events except the 0.1% AEP event. Flood mapping will be limited to the extent where boundary conditions do not impact on flood levels.

Structure blockage (sensitivity test 3)

6.7.9 Blockage analysis has been performed to determine the risk to the Proposed Scheme during extreme flood events (0.1% AEP) using a normal depth boundary condition. Blockages have been applied to existing culverts and the Proposed Scheme alignment as follows:

- 10% blockage to the existing culvert module by setting a blockage depth equal to 10% of flow depth; and
- 2% or 10% blockage depth as appropriate to the bridge / viaduct structure by raising internal bridge cross sections by a level equal to 2% of depth at the cross section and increasing the pier width by 2% of the flow top width.

Table 49: Blockage analysis

Model	**Flood level (upstream of Proposed Scheme - 0.1% AEP), mAOD**
Post development model	90.815
Blockage analysis	90.820

6.7.10 Introducing a blockage to the Proposed Scheme viaduct and downstream A452 Kenilworth Road culvert results in a minor increase of 5mm in the estimated flood level upstream of the route.

Levees (sensitivity test 4)

6.7.11 The model has been tested to determine the impact on flood levels of introducing levees to control the flow into the shallow floodplain.

Table 50: Levees

Model	**Flood level (upstream of Proposed Scheme - 1% AEP + cc), mAOD**
Post development model	90.776
Post development model with levees	90.777

6.7.12 Introducing levees to the cross sections results in no change to upstream flood level. However, the levees introduce uncertainty in the extreme flood levels as the level fluctuates around the levee profile on the right hand bank. This further suggests that the model would benefit from assessment with a 2D model at detailed design stage.

6.8 Uncertainty

6.8.1 Flood levels upstream of the proposed route will be used to inform the design levels. An uncertainty factor will be applied to these levels, calculated using the fluvial freeboard guidance note, R&D technical report W187 published by the Environment Agency.

Table 51: Proposed Scheme design flood levels

Flood flow	Modelled level, mAOD	Uncertainty allowance, m	Design flood level, mAOD
1% AEP + 20%	90.776	0.093	90.870
0.1% AEP (including blockage analysis)	90.815	0.108	90.923

6.9 Model results tables

Table 52: Baseline model results

Baseline, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
16	92.832	92.862	92.886	92.902	92.924	92.94	92.964
15	92.407	92.447	92.462	92.482	92.501	92.518	92.534
14	91.758	91.839	91.876	91.905	91.937	91.96	91.976
13	91.31	91.365	91.396	91.417	91.445	91.463	91.495
12	90.996	91.035	91.061	91.086	91.12	91.151	91.188
11	90.788	90.842	90.875	90.903	90.938	90.968	90.997
10.5	90.619	90.655	90.685	90.711	90.745	90.769	90.806
8.4	90.521	90.594	90.645	90.676	90.71	90.734	90.77
8.3	89.962	90.035	90.085	90.128	90.173	90.188	90.133
8.2	89.744	89.796	89.828	89.858	89.895	89.937	90.058
8	89.605	89.672	89.704	89.707	89.741	89.843	90.028
7.5	89.218	89.322	89.4	89.497	89.67	89.811	90.017
7	89.004	89.158	89.267	89.372	89.602	89.762	89.981
6	88.804	88.935	89.026	89.112	89.377	89.534	89.742
5	88.764	88.899	88.993	89.081	89.358	89.518	89.731
4	88.521	88.626	88.69	88.749	88.833	88.9	88.99
3.5	88.389	88.481	88.539	88.593	88.67	88.732	88.817
3	88.058	88.158	88.226	88.289	88.368	88.423	88.497
2.75	87.779	87.857	87.905	87.952	88.013	88.057	88.101
2.5	87.677	87.745	87.782	87.824	87.874	87.909	87.893
2	87.442	87.523	87.583	87.642	87.736	87.796	87.877
1.5	87.179	87.285	87.347	87.402	87.322	87.36	87.411
1	86.956	86.626	86.679	86.736	87.051	87.086	87.135

Table 53: Post development model results

Post-development model, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
16	92.832	92.862	92.886	92.902	92.924	92.94	92.964
15	92.407	92.447	92.462	92.482	92.501	92.518	92.534
14	91.758	91.839	91.876	91.905	91.937	91.96	91.976
13	91.31	91.365	91.396	91.417	91.445	91.463	91.495
12	90.996	91.035	91.061	91.086	91.12	91.151	91.188
11	90.788	90.842	90.875	90.903	90.938	90.968	90.998
10.5	90.619	90.655	90.684	90.709	90.746	90.773	90.809
8.4	90.521	90.59	90.642	90.673	90.712	90.74	90.776
8.3	89.964	90.036	90.087	90.13	90.165	90.164	90.164
8.2	89.708	89.771	89.815	89.855	89.921	89.991	90.106
8	89.443	89.498	89.551	89.609	89.735	89.849	90.028
7.5	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
6	88.804	88.935	89.027	89.113	89.377	89.534	89.743
5	88.764	88.899	88.993	89.081	89.359	89.518	89.731
4	88.521	88.626	88.692	88.751	88.834	88.9	88.99
3.5	88.389	88.482	88.541	88.595	88.672	88.733	88.818
3	88.058	88.158	88.226	88.289	88.368	88.423	88.497
2.75	87.779	87.857	87.905	87.952	88.013	88.057	88.101
2.5	87.677	87.745	87.782	87.824	87.874	87.909	87.893
2	87.442	87.523	87.583	87.642	87.736	87.796	87.877
1.5	87.179	87.285	87.347	87.402	87.322	87.36	87.411
1	86.956	86.626	86.679	86.736	87.051	87.086	87.135

Table 54: Baseline and post development comparison

Comparison, m							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.001
10.5	0.000	0.000	-0.001	-0.002	0.001	0.004	0.003
8.4	0.000	-0.004	-0.003	-0.003	0.002	0.006	0.006
	-	-	-	-	-	-	-
8.2	-0.036	-0.025	-0.013	-0.003	0.026	0.054	0.048
8	-0.162	-0.174	-0.153	-0.098	-0.006	0.006	0.000
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
6	0.000	0.000	0.001	0.001	0.000	0.000	0.001
5	0.000	0.000	0.000	0.000	0.001	0.000	0.000
4	0.000	0.000	0.002	0.002	0.001	0.000	0.000
3.5	0.000	0.001	0.002	0.002	0.002	0.001	0.001
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.75	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000

7 River Blythe Bypass model

7.1 Introduction

7.1.1 The hydraulic models cover a localised reach of a watercourse which is a tributary of the River Blythe. The section of watercourse modelled extends from grid reference 422368, 281323 upstream to grid reference 421558, 280845 at the confluence with the River Blythe; a total reach length of 1.65km around the proposed structure and a predominantly rural catchment area of 7.5km^2.

7.1.2 The route crosses the watercourse at grid reference 421846, 280869.

7.2 Hydrology

Derivation of inflows

7.2.1 A preliminary hydrological investigation has been undertaken in order to understand the magnitude of flows generated by the catchment up to a point a short distance downstream the proposed crossing point of the route.

7.2.2 The catchment is essentially rural, although it is likely that the channel of the watercourse has been modified so that it serves as a land drainage and field boundary feature. The most significant crossing upstream of the Proposed Scheme is the A452 Kenilworth Road culvert.

7.2.3 Downstream of the A452 Kenilworth Road culvert the channel bifurcates with the main Horn Brook channel flowing in a northerly direction to the River Blythe and the channel of interest in this report flowing in a westerly direction. Site observations suggest that the northern channel receives a significantly greater proportion of flow than the western "bypass" channel. A stream junction has been incorporated into the model to generate the flow split.

7.2.4 The flows generated by the ReFH spreadsheet are shown in Table 55 below.

Table 55: Peak flow calculation results using ReFH

Annual exceedence probability (AEP)	Total flow (m^3/s)
50%	1.52
20%	1.99
10%	2.36
5%	2.75
2%	3.35
1.33%	3.66
1%	3.90
1% AEP + 20%	4.68
0.1%	7.05

7.2.5 These flows have been applied as a single hydrograph at the upper Horn Brook reach. In practice the flows at this location would be lower and lateral inflows should be applied downstream to more accurately assess the flows in the upper portion of the model. The single hydrograph approach will overestimate the floodplain in the upstream reach of the Horn Brook. At this stage of the project the slight over estimate of flows in the upper reach of the model is considered acceptable and can be improved at detailed design stage.

7.3 Hydraulic models

Overview

7.3.1 1D unsteady state models (HEC-RAS) were used to represent the watercourse main channels and rural floodplains for the pre- and post-development scenarios and a range of storm events with 50%, 20%, 10%, 5%, 2%, 1% and 0.1% AEPs.

7.3.2 A 1D unsteady state model was required to accurately assess the flow split at the junction and a previously constructed steady state model was updated for the purpose. A 1D model was considered appropriate for this river reach due to the relatively uniform, narrow floodplain. This choice of model allows the representation of the main features present in the area of interest and the estimation of their effects on extreme water levels. The main features in the modelled extent are:

- water levels and conveyance along the River Blythe Bypass and Horn Brook, taking into account the channels' geometry and roughness;
- water levels and conveyance across the river's floodplains, taking into account ground levels, land uses and obstructions to flow (e.g. road embankments, buildings, etc.); and
- impact on water levels and flood flow conveyance of the Proposed Scheme

7.3.3 It should be noted that the confluences of the watercourses are complex due to the modified nature of the catchment to provide land drainage and facilitate the construction of the A452 Kenilworth Road.

7.4 Baseline model

7.4.1 All models are located within the RIVERBLYTHEBYPASSv4.prj file.

Table 56: Model files

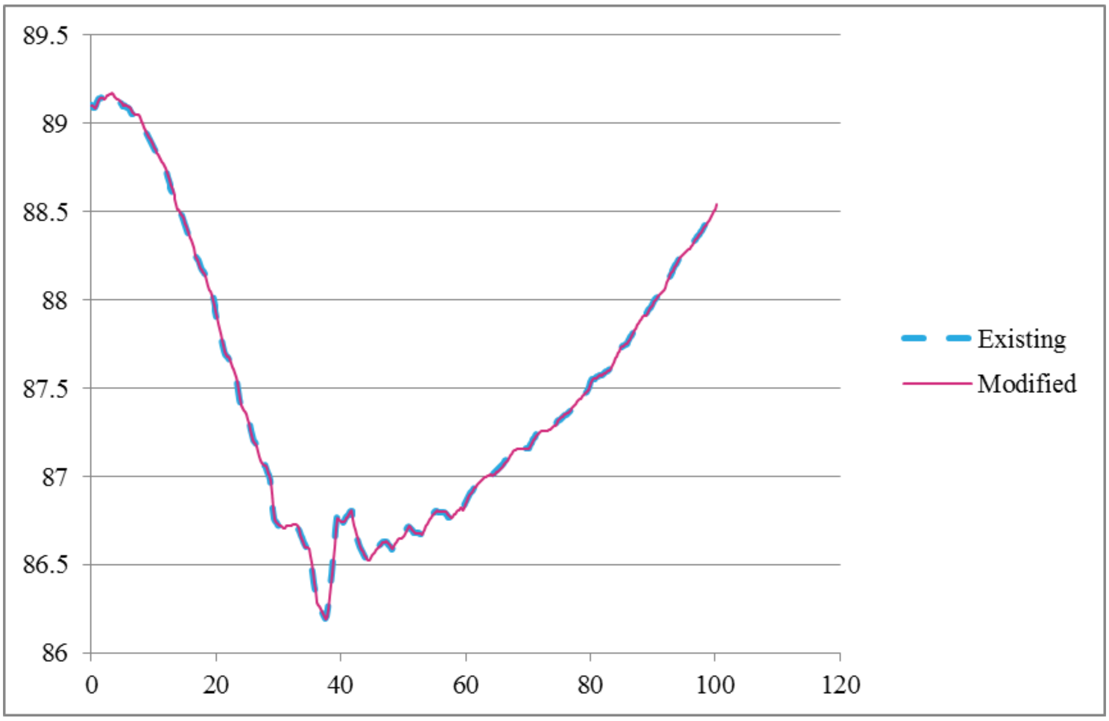
Model title	Geometry file title
Baseline	Baseline model
Post development model (Proposed Scheme only)	Post development model Proposed Scheme only
Post development model	Post development modelv3.7

Topography

7.4.2 LiDAR data (refer to Section 2.2) was used to obtain ground levels across the reach extent. Cross sections were derived from LiDAR data inserted into ArcGIS as a raster image and the number of points in each cross section adjusted to comply with HEC-RAS's 500 station maximum limit. Road deck information was also obtained using the same method.

7.4.3 The reduction in station points has been achieved without losing definition of either the floodplains or channel. This was possible due to the relatively short cross section lengths and the high resolution of the LiDAR data, enabling station points to be removed without altering the geometric shape of floodplain or channel. A typical representation of the cross sections showing the before and after scenarios are included below for information.

Figure 19: Typical cross section showing reduced station data

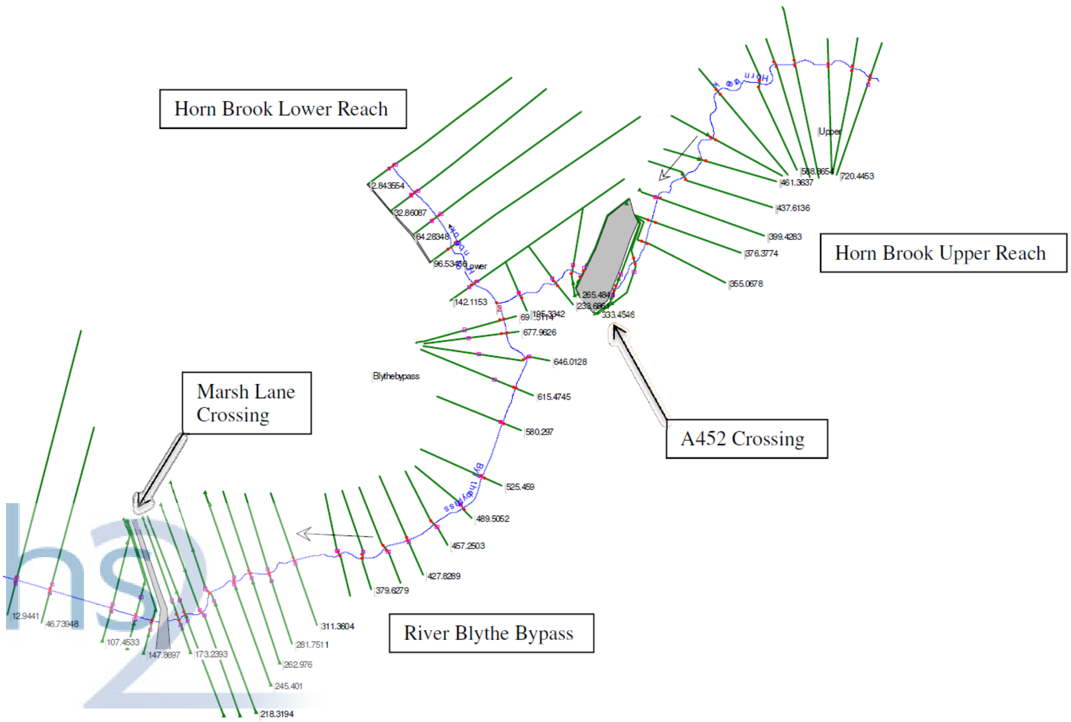


7.4.4 All field boundaries are assumed to enable conveyance of flood flows.

Cross-section location

7.4.5 Cross section locations were selected in relation to flood flow direction and existing and proposed crossings to be modelled including an existing culvert and the River Blythe Bypass culvert. Cross sections locations are shown in Figure 20.

Figure 20: Cross section locations (baseline model)



7.4.6 Preferred cross section spacing was initially determined using the Samuels equation which indicates a cross section spacing of approximately 80m at varying points along the reach. In general the suggested spacing has been set much closer to incorporate various watercourse crossings and improve the GIS flood mapping. A sensitivity check has been undertaken with cross sections applied at the correct spacing which confirmed a change in water level of less than 20mm at the upstream cross section of the Horn Brook. Given the size of watercourse and the sensitivity accuracy the shorter cross section spacing is considered acceptable.

Land use and roughness coefficients

7.4.7 Roughness coefficients were specified as Manning's 'n' values. Site observations were not possible for much of the reach and global roughness values were applied. Ordnance Survey MasterMap data and aerial photography were used to establish land uses with appropriate manning roughness values applied to suit.

Ineffective flow areas and hydraulic modelling

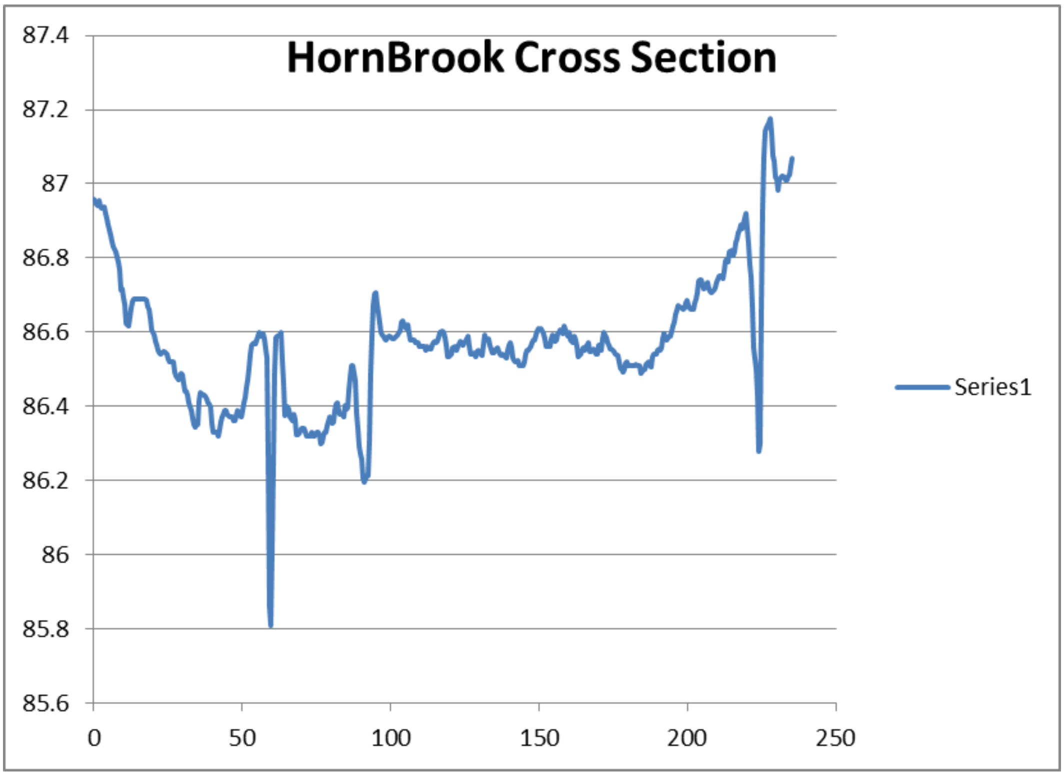
7.4.8 Ineffective flow areas were applied at the following locations:

- on the upstream and downstream side of culverts and bridges to represent areas not conveying flow due to upstream or downstream restrictions;
- to areas of no conveyance in the downstream cross sections which intersect impounded fishing lakes and a small pond; and
- in the section of upper Horn Brook where flow is able to discharge to floodplain in a small number of locations and by a backwater effect but is largely separated from the main channel.

7.4.9 The Horn Brook catchment downstream of the A452 Kenilworth Road has been heavily modified with artificial land drainage ditches excavated alongside the channel. At the downstream end of the modelled reach the drainage channel is at a lower elevation than the main Horn Brook channel and is likely to drain any flood flows which overtop the left bank of the Horn Brook in severe flood events. A cross section is provided below (Figure 21) which shows the main Horn Brook channel, left overbank floodplain and artificial drainage channel.

7.4.10 The main Hornbrook channel is the central feature. The channels on the left and right bank are artificial drainage ditches. The natural floodplain appears to be located over the left bank of the watercourse but is interrupted and modified by the artificial drainage channel.

Figure 21: Typical cross section showing reduced station data



7.4.11 To simplify the model the Horn Brook cross sections have been cut at the right bank of the left hand drainage channel and a lateral weir inserted to remove flow from model which is assumed to enter the drainage ditch system. The drainage ditch has not been modelled as a separate river reach and hence the floodplain extents for the downstream Horn Brook will omit this area of floodplain. At detailed design stage the model may be enhanced by incorporating the artificial drainage channels as separate river reaches.

Downstream boundary condition

7.4.12 The proposed baseline model assumes a 'normal depth' level-flow relationship as a downstream boundary conditions (Horn Brook and Blythe Bypass) for all flows. An additional simulation has been run for the 1% AEP + cc event using the downstream Blythe 1% AEP + cc flood level as a boundary condition. The River Blythe 1% AEP + cc flood level has been taken from the Tuflow model constructed to assess the Blythe Viaduct structure (Volume 5: Appendix WR-004-017). The extrapolated 1% AEP + climate change flood level from the River Blythe model is 86.30m AOD and the 0.1% AEP flood level is 86.38mAOD.

Table 57: Boundary conditions

AEP	Revised boundary conditions based on Blythe Tuflow model
50%, 20%, 10%, 5% & 2%, 1%, 1% AEP + 20%, 0.1%	Normal depth For both boundary conditions
1% AEP + cc	86.15m AOD Blythe Bypass Normal depth for Horn Brook

7.4.13 The Horn Brook model extent does not extend to the confluence with the Blythe and comparison of the levels confirms that the Blythe floodplain would not extend up the reach to the extent of the modelled boundary. Hence a normal depth boundary condition is sufficient.

7.4.14 No joint probability analysis has been undertaken on the Blythe and Blythe Bypass culvert and the likelihood of combined extreme flood events is probably unlikely given the relative catchment sizes. The application of 1% and 0.1% flood levels for the boundary condition is a conservative assessment and will be used for assessing the impact of the Proposed Scheme crossing and for the post development design levels. Flood mapping will be plotted on the basis of the normal depth boundary conditions.

7.4.15 A sensitivity analysis has been undertaken on the boundary condition applied for the 1% + 20% climate change flow to determine the sensitivity of inaccuracy in existing flood levels and also the impact on flow split between the Blythe Bypass and Horn Brook reaches.

Runtime parameters and model performance

7.4.16 The default HEC-RAS values were used in all simulations. Expansion and contraction coefficients were set to the default of 0.3 and 0.1 respectively.

7.4.17 The nature of the river reach has resulted in significant variation in cross sections leading to warnings regarding the large change in conveyance between upstream and downstream cross sections.

Hydraulic rating curves

7.4.18 All hydraulic property curves have been inspected for the relevant structures and are considered acceptable for the analysis. The deck level of the culvert on the River Blythe Bypass creates varying curves which may lead to instability in the event the deck is overtopped. Flood levels were monitored for stability.

Unsteady computations and stability

7.4.19 The model has been run using a normal flow routine as Froude numbers are all less than one and therefore subcritical.

7.4.20 The computational time step has been set to 30 seconds based on a Courant condition of one based on a cross section spacing of 50.

7.4.21 Model parameters have been left to default settings apart from the Theta weighting which was reduced to 0.6 while maintaining model stability.

Historic data

7.4.22 There are no historic / observed flood levels or gauged data available for this reach.

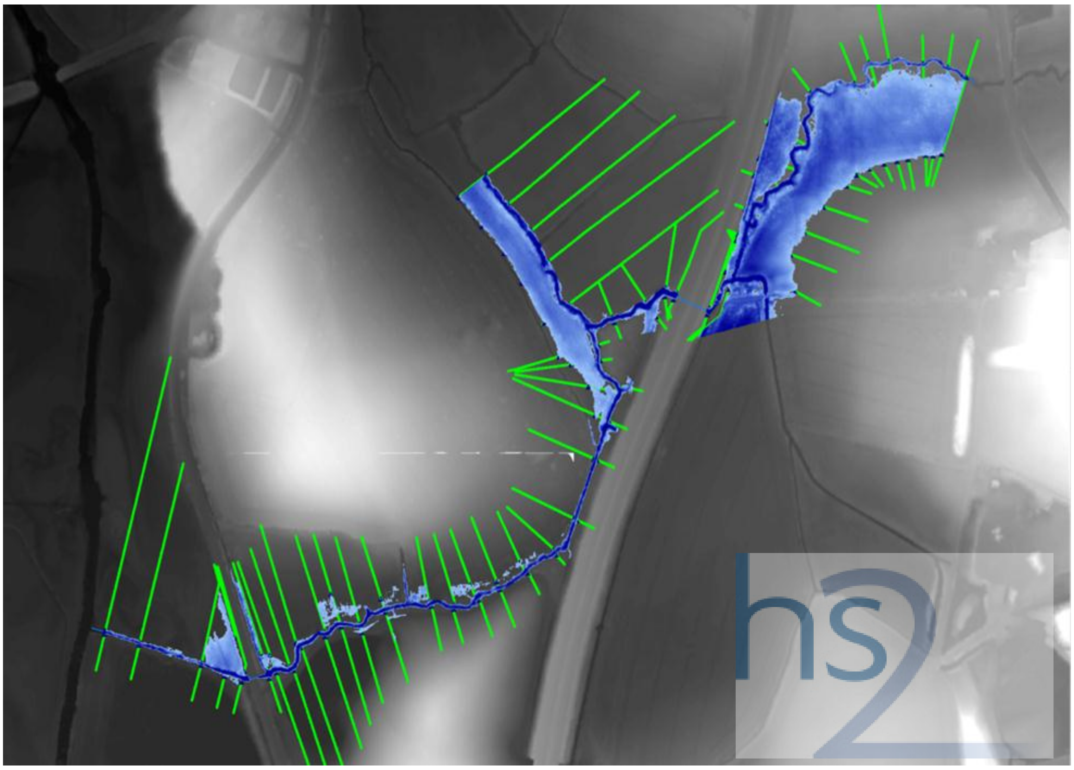
Baseline model results

7.4.23 The baseline model was run for the 50%, 20%, 10%, 5%, 2%, 1% and 0.1% AEP flows. The estimate flood levels and flood extents are shown in Table 58 and Figure 22.

Table 58: Baseline model results

AEP	Estimated level upstream of River Blythe Bypass culvert, (XS 355), mAOD	Estimated level U upstream of River Blythe Bypass culvert, (XS 379), mAOD
50%	86.222	86.249
20%	86.288	86.313
10%	86.327	86.35
5%	86.376	86.397
2%	86.407	86.427
1%	86.438	86.458
1% AEP + 20%	86.471	86.49

Figure 22: Baseline flood extents (1% AEP + cc)



7.5 Post-development model

Overview

7.5.1 The post development model includes a 4.5m culvert which carries the route over the Blythe Bypass channel.

Post-development model results

7.5.2 The post-development model was run for the same flow and boundary condition events as the baseline model.

7.5.3 The proposed model results are shown in Table 59. The model predicts a negligible change in flood levels resulting from the new crossing. Flood levels shown a very minor reduction due to a slight streaming of flow through the culvert structure.

Table 59: Post-development model results

AEP	Estimated level U upstream of River Blythe Bypass culvert (XS 355 – Blythe Bypass), mAOD	Post development estimated level U upstream of River Blythe Bypass culvert (XS 355 – Blythe Bypass), mAOD	Maximum estimated change in peak water level, m
50%	86.222	86.222	0.000
20%	86.288	86.286	-0.002
10%	86.327	86.323	-0.004
5%	86.376	86.373	-0.003
2%	86.407	86.404	-0.003
1%	86.438	86.437	-0.001
1% AEP + 20%	86.471	86.470	-0.001

7.5.4 The model results indicate no significant impact as a result of the proposed Blythe Bypass culvert.

A452 Kenilworth Road model results

7.5.5 The post development model has been updated to include the A452 Kenilworth Road culvert and Horn Brook diversion upstream of the existing A452 Kenilworth Road culvert. The proposed river diversion is based on an approximate earthworks model and will require refinement at detailed design stage.

7.5.6 The existing culvert will remain in-situ to provide a private means of access.

Table 60: Post development model results

AEP	Estimated level upstream Proposed Scheme crossing, (XS 588 – Horn Brook), mAOD	Post development estimated Level upstream Proposed Scheme crossing, (XS 588 – Horn Brook), mAOD	Maximum estimated change in peak water level,m
50%	87.949	87.95	0.001
20%	87.978	87.975	-0.003
10%	88.015	87.993	-0.022
5%	87.994	88.015	0.021
2%	88.034	88.031	-0.003
1%	88.056	88.051	-0.005
1% AEP + 20%	88.084	88.079	-0.005

7.5.7 With the A452 Kenilworth Road culvert crossing and Horn Brook diversion there is predicted to be a slight increase in upstream flood levels upstream of the watercourse diversion of up to 20mm for the 10% AEP event. The increase in flood level is predominantly caused by slight instability within the model which is highlighted by the corresponding decrease for the 10% AEP event. The 1% AEP and the 1% AEP+ cc events show negligible changes in flood level.

7.5.8 Some minor changes in flood levels occur downstream at mid-duration return periods occurring because of minor variations in the flow split between the Blythe Bypass and main Horn Brook and the slight instability in the model for the 10% and 5% events

7.6 Sensitivity testing

Overview

7.6.1 Given the absence of calibration data, surveyed levels of flooding or historic flood outlines for the modelled reach of the River Blythe Bypass (other than flood extents extending upstream from the River Blythe), a range of sensitivity tests were undertaken for the most critical assumptions made during the model build. These are:

- change to culvert dimension beneath Marsh Lane and the A452 Kenilworth Road (sensitivity test 1 & 2);
- roughness coefficients (sensitivity test 3);
- downstream boundary condition (sensitivity test 4);
- stream junction modelling (sensitivity test 5); and
- blockage of proposed and existing structure (sensitivity test 6).

7.6.2 Sensitivity tests 1 to 3 were carried out for the 1% AEP plus climate change event, while sensitivity test 4 was undertaken for the 0.1% AEP event and will also be used to provide design 0.1% AEP flood level for the Proposed Scheme. Results are presented in the following sections.

Existing Marsh Lane culvert dimension (sensitivity test 1)

7.6.3 The existing culvert beneath Marsh Lane has not been surveyed due to restricted access at the time of writing this report. A culvert dimension has been estimated based on a number of factors including channel dimension, aerial photography which shows the culvert crossing in plan, other culverts in the Blythe catchment area.

7.6.4 An arched culvert with 1.2m span and 1m depth has been assumed. A sensitivity analysis has been undertaken to determine the impact of increasing or decreasing the culvert dimension. The sensitivity analysis has been run using the 1% AEP plus climate change event.

Table 61: Sensitivity test – culvert dimensions

Culvert dimensions*	Flood level (downstream of Proposed Scheme) – XS 262.976, mAOD
1m x 0.5m Arch	86.463
1.2m x 1m Arch	86.265
1.5m x 1.2m box culvert	86.246
2m x 1.2m box culvert	86.236

*The possible depth of culvert is restricted by the road deck level across Marsh Lane and is unlikely to exceed 1.2m based on the topographic information.

7.6.5 The sensitivity analysis shows a significant difference of 227mm across the range of culverts. A smaller culvert provides a worst case analysis of upstream flood risk to the development and a 1.2m x 1m arch culvert has been adopted for all further model runs. The choice of culvert will not affect the assessment of the relative impact of the Proposed Scheme crossing but the lack of information on the existing culvert does limit the accuracy of the flood mapping results. It should also be noted that the culvert dimensions become more critical in the event of an increase in the flow entering the Blythe Bypass channel.

Existing A452 Kenilworth Road culvert dimension (sensitivity test 2)

7.6.6 The existing culvert beneath the A452 Kenilworth Road has not been surveyed due to restricted access at the time of writing this report. A culvert dimension has been estimated based on a number of factors including channel dimension, aerial photography which shows the culvert crossing in plan.

7.6.7 A box culvert with 4m span and 1.5m depth has been assumed. A sensitivity analysis has been undertaken to determine the impact of increasing or decreasing the culvert dimension. The sensitivity analysis has been run using the 1% AEP plus climate change event.

Table 62: Sensitivity test – culvert dimensions

Culvert dimensions	Flood level (immediately upstream of A452 Kenilworth Road XS 299), mAOD	Flood level (upstream of A452 XS 376), mAOD
2.5m x 1.5m box culvert	87.721	87.867
3m x 1.5m box culvert	87.595	87.836
4m x 1.5m box culvert	87.427	87.836
4.5m x 1.5m box culvert	87.393	87.836

7.6.8 The sensitivity analysis shows a significant water level difference of >500mm across the range of culverts immediately upstream of the culvert. The watercourse channel rises steeply beyond the culvert and the water level increase dissipates less than 100m upstream.

7.6.9 The 4m by 1.5m culvert will be adopted for all model runs as this is the best estimate based on the information available. Further survey information will be required at detailed design stage.

Roughness coefficients (sensitivity test 3)

7.6.10 The baseline model's sensitivity to roughness coefficients was assessed by considering ±20% variations on the adopted Manning's 'n' values. Flows have been determined using the 2% AEP event as the 1% AEP event is heavily influenced by the downstream flood level from the Blythe and would not reflect the change in conveyance imposed by variations to roughness values.

Table 63: Sensitivity test – roughness values

Sensitivity test	Flood level (upstream of Proposed Scheme alignment - 1% AEP + cc) XS 262.976, mAOD
Modelled roughness values -20%	86.205
Modelled roughness values	86.265
Modelled roughness values +20%	86.339

7.6.11 With a 20% increase to Manning's 'n' values the estimate flood level shows an increase of 74mm. The increase occurs because a higher proportion of flow enters the Blythe Bypass channel.

7.6.12 With a 20% decrease to Manning's 'n' values the estimate flood level shows a decrease of 60mm. Again the decrease is due to a change in the proportion of flow entering the Blythe Bypass channel.

7.6.13 Given the significant in Manning's roughness a higher roughness factor will be applied to model for the lower reach of the Horn Brook to ensure a higher proportion of flow enters the Blythe channel.

Downstream boundary condition (sensitivity test 4)

7.6.14 The baseline model's sensitivity to the downstream boundary condition was assessed by considering variation in downstream boundary condition by ± 0.5m on the adopted 1% AEP plus climate change boundary level.

Table 64: Downstream boundary condition

Downstream boundary condition slope	Horn Brook downstream level, mAOD	Blythe Bypass downstream level, mAOD	Flood level (upstream of Proposed Scheme - 1% AEP + cc) XS 262.976,mAOD
Blythe Bypass normal depth 0.0015 Horn Brook normal depth 0.002	86.663	85.738	86.296
Blythe Bypass normal depth 0.002 Horn Brook normal depth 0.003	86.636	85.699	86.299
Blythe Bypass normal depth 0.002 Horn Brook normal depth 0.0015	86.680	85.699	86.299

Downstream boundary condition slope	Horn Brook downstream level, mAOD	Blythe Bypass downstream level, mAOD	Flood level (upstream of Proposed Scheme - 1% AEP + cc) XS 262.976,mAOD
Blythe Bypass normal depth 0.002 Horn Brook normal depth 0.002	86.663	85.699	86.299
Blythe Bypass normal depth 0.003 Horn Brook normal depth 0.002	86.663	85.648	86.303
Blythe Bypass normal depth 0.002 Horn Brook normal depth 0.0001	86.754	85.699	86.298

7.6.15 Varying the downstream normal depth boundary conditions results in a negligible change in water levels at the Proposed Scheme crossing and the estimated normal depths will be used for all modelled boundary conditions.

Stream junction sensitivity (sensitivity test 5)

7.6.16 The extent of flow entering the Blythe Bypass channel at the junction with the Horn Brook is critical in determining the flood risk impact of the proposed structure. The flow split is governed primarily by the channel capacity in each reach but the calculation method also impacts the results.

7.6.17 Two variations of the model have been run, the first using the energy balance method and second using a forced water surface profile.

7.6.18 The peak flow entering the Blythe Bypass channel for the 1% AEP + cc event is shown in Table 65.

Table 65: Sensitivity test – stream junction boundary

Sensitivity test	Peak flow (m^3/s)
Energy balance	0.870
Forced water surface	0.870

7.6.19 Varying the modelling approach at the stream junction causes no change in flow entering the Blythe Bypass. Both models achieve a stable model run.

7.6.20 The primary control of flow split at the junction is the downstream channel capacity. The table below identifies the upstream channel capacity (as cross sectional area) for both watercourses. The Horn Brook cross section of the main channel is typically 1.5x the capacity of the Blythe Bypass channel and has a slightly steeper gradient in the upper portion of the reach.

Table 66: Stream junction sensitivity test

Elevation, mAOD	Horn Brook (m^2)	Blythe Bypass (m^2)
86.45	0.33	0.11
86.61	0.83	0.35
86.77	1.49	0.8
86.93	2.31	1.52
87.32	4.38	3
87.4	4.8	3.38
87.56	5.63	4.12
87.95	7.71	5.6

7.6.21 As the upstream channel geometry is important a survey of this arrangement would be required for detailed design to enable the flow split to be accurately derived.

Structure blockage (sensitivity test 6)

7.6.22 Blockage analysis has been performed to determine the risk to the Proposed Scheme during extreme flood events (0.1% AEP). Blockages have been applied to existing culverts and the proposed route as follows:

- 10% blockage to the existing culvert module by setting a blockage depth equal to 10% of flow depth; and
- 2% or 10% blockage depth as appropriate to the bridge / viaduct structure by raising internal bridge cross sections by a level equal to 2% of depth at the cross section and increasing the pier width by 2% of the flow top width.

7.6.23 No blockage scenario has been run for the A452 Kenilworth Road culvert as there is no requirement to consider the 0.1% AEP flood level for infrastructure other than the Proposed Scheme.

7.6.24 The blockage analysis has been performed using the full Horn Brook flow as a steady state model resulting in a significantly elevated 0.1% AEP flood level which is only used to demonstrate the level of river protection to the Proposed Scheme.

Table 67: Blockage analysis

Model	Flood level (upstream of Proposed Scheme alignment - 0.1% AEP), mAOD
Blockage analysis	87.284

Uncertainty

7.6.25 Flood levels upstream of the proposed route will be used to inform the design levels. An uncertainty factor will be applied to these levels, calculated using the fluvial freeboard guidance note, R&D technical report W187 published by the Environment Agency.

Table 68: Design flood levels

AEP	Modelled level, mAOD	Uncertainty allowance, m	Design flood level, mAOD
1% AEP + 20%	86.921	0.181	87.102
0.1% (including blockage analysis)*	87.284	0.201	87.485

*0.1% AEP flood levels are significantly over estimated but demonstrate the level of protection to the Proposed Scheme

7.7 Model results tables

Table 69: Baseline model results

Baseline, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
720.4453	88.451	88.476	88.493	88.483	88.502	88.515	88.533
700.7502	88.348	88.376	88.412	88.394	88.428	88.444	88.461
674.009	88.229	88.255	88.285	88.268	88.301	88.318	88.337
640.5771	88.087	88.109	88.138	88.122	88.155	88.173	88.196
621.841	88.02	88.045	88.077	88.059	88.095	88.113	88.137
588.8654	87.949	87.978	88.015	87.994	88.034	88.056	88.084
542.6458	87.866	87.898	87.946	87.919	87.968	87.995	88.027
492.9169	87.808	87.841	87.895	87.865	87.919	87.947	87.982
461.3637	87.783	87.811	87.866	87.835	87.889	87.917	87.952
437.6136	87.753	87.775	87.824	87.796	87.85	87.878	87.916
399.4283	87.631	87.679	87.747	87.71	87.779	87.817	87.861
376.3774	87.562	87.631	87.712	87.669	87.747	87.789	87.835
355.0678	87.542	87.62	87.703	87.659	87.739	87.783	87.829
333.4546	87.324	87.397	87.485	87.441	87.526	87.572	87.635
299.7251	87.05	87.125	87.231	87.176	87.279	87.343	87.422
265.4841	87.096	87.174	87.289	87.228	87.341	87.4	87.467
255.7566	87.011	87.086	87.197	87.138	87.248	87.309	87.372
233.6861	86.97	87.045	87.159	87.098	87.212	87.276	87.35
195.3342	86.842	86.893	86.954	86.92	86.975	86.996	87.021
142.1153	86.842	86.893	86.954	86.92	86.975	86.996	87.021
96.53466	86.777	86.839	86.896	86.864	86.908	86.917	86.929
64.28348	86.727	86.79	86.806	86.803	86.816	86.83	86.852
32.86087	86.611	86.651	86.687	86.669	86.704	86.723	86.745
2.843554	86.524	86.552	86.6	86.575	86.621	86.642	86.662
691.5114	86.842	86.893	86.954	86.92	86.975	86.996	87.021
677.9626	86.832	86.885	86.948	86.913	86.97	86.991	87.017
646.0128	86.816	86.869	86.932	86.897	86.954	86.976	87.002
615.4745	86.794	86.845	86.906	86.872	86.928	86.949	86.976
580.297	86.755	86.802	86.859	86.828	86.878	86.898	86.922
525.459	86.632	86.677	86.732	86.701	86.752	86.772	86.797

Baseline, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
489.5052	86.381	86.437	86.51	86.468	86.537	86.563	86.594
457.2503	86.351	86.409	86.485	86.442	86.513	86.54	86.571
427.8289	86.316	86.375	86.453	86.41	86.482	86.509	86.54
404.8746	86.3	86.361	86.443	86.397	86.472	86.5	86.532
379.6279	86.247	86.311	86.395	86.348	86.426	86.457	86.489
355.6248	86.22	86.286	86.373	86.325	86.405	86.437	86.471
311.3604	86.161	86.229	86.322	86.269	86.355	86.39	86.423
281.7511	86.142	86.211	86.305	86.251	86.338	86.373	86.406
262.976	86.111	86.184	86.28	86.225	86.318	86.356	86.39
245.401	86.098	86.171	86.267	86.213	86.305	86.343	86.376
218.3194	86.086	86.16	86.258	86.202	86.296	86.335	86.368
197.138	86.057	86.136	86.239	86.181	86.279	86.319	86.352
181.0515	86.051	86.131	86.235	86.177	86.275	86.316	86.348
173.2393	86.051	86.133	86.236	86.178	86.277	86.318	86.35
147.8697	86.019	86.088	86.172	86.126	86.204	86.235	86.252
131.2385	86.017	86.087	86.172	86.125	86.204	86.235	86.252
107.4533	85.762	85.816	85.882	85.845	85.908	85.933	85.947
46.73948	85.585	85.633	85.694	85.66	85.718	85.74	85.752
12.9441	85.503	85.554	85.62	85.583	85.645	85.668	85.681

Table 70: Post development model results

Post-development, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
720.4453	88.454	88.489	88.494	88.497	88.501	88.515	88.534
700.7502	88.352	88.379	88.395	88.414	88.43	88.444	88.462
674.009	88.235	88.257	88.273	88.29	88.306	88.321	88.339
640.5771	88.092	88.112	88.126	88.144	88.158	88.175	88.197
621.841	88.024	88.046	88.06	88.08	88.095	88.113	88.137
588.8654	87.95	87.975	87.993	88.015	88.031	88.051	88.079
542.6458	87.849	87.88	87.909	87.94	87.957	87.979	88.014
533.5641	87.739	87.785	87.803	87.837	87.86	87.893	87.951
509.8936	87.706	87.754	87.763	87.793	87.818	87.855	87.924
458.7506	87.493	87.59	87.638	87.672	87.713	87.774	87.866
405.8468	87.286	87.358	87.425	87.525	87.615	87.709	87.824
333.4546	87.271	87.335	87.38	87.434	87.482	87.538	87.614
299.7251	87.052	87.127	87.178	87.235	87.283	87.347	87.433
265.4841	87.097	87.176	87.23	87.292	87.344	87.403	87.474
255.7566	87.013	87.088	87.14	87.201	87.253	87.313	87.386
233.6861	86.971	87.047	87.1	87.162	87.218	87.281	87.357
195.3342	86.843	86.894	86.915	86.948	86.965	86.989	87.024
142.1153	86.843	86.894	86.915	86.948	86.965	86.989	87.024
96.53466	86.778	86.841	86.863	86.883	86.885	86.903	86.926
64.28348	86.727	86.792	86.822	86.855	86.856	86.856	86.856
32.86087	86.611	86.653	86.681	86.704	86.71	86.725	86.745
2.843554	86.523	86.553	86.576	86.597	86.623	86.644	86.662
691.5114	86.843	86.894	86.915	86.948	86.965	86.989	87.024
677.9626	86.833	86.886	86.907	86.941	86.959	86.985	87.02
646.0128	86.816	86.87	86.891	86.925	86.943	86.969	87.005
615.4745	86.794	86.845	86.866	86.9	86.917	86.942	86.979
580.297	86.755	86.803	86.822	86.852	86.868	86.891	86.925
525.459	86.634	86.678	86.696	86.726	86.742	86.767	86.8
489.5052	86.382	86.438	86.462	86.501	86.524	86.556	86.598
457.2503	86.352	86.41	86.435	86.475	86.499	86.532	86.575
427.8289	86.317	86.376	86.402	86.444	86.468	86.501	86.544

Post-development, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
404.8746	86.301	86.362	86.389	86.432	86.457	86.492	86.536
379.6279	86.249	86.312	86.339	86.384	86.41	86.448	86.493
355.6248	86.222	86.287	86.316	86.362	86.389	86.428	86.475
311.3604	86.165	86.234	86.265	86.313	86.341	86.382	86.43
281.7511	86.144	86.215	86.247	86.296	86.324	86.366	86.413
262.976	86.113	86.186	86.219	86.27	86.299	86.344	86.392
245.401	86.1	86.173	86.206	86.257	86.287	86.332	86.379
218.3194	86.088	86.162	86.196	86.248	86.278	86.323	86.37
197.138	86.059	86.139	86.174	86.229	86.26	86.307	86.354
181.0515	86.052	86.133	86.169	86.224	86.256	86.304	86.351
173.2393	86.053	86.135	86.17	86.226	86.257	86.305	86.353
147.8697	86.02	86.09	86.12	86.164	86.189	86.226	86.252
131.2385	86.018	86.089	86.119	86.164	86.189	86.226	86.253
107.4533	85.763	85.817	85.84	85.876	85.895	85.925	85.948
46.73948	85.586	85.634	85.655	85.688	85.706	85.733	85.753
12.9441	85.504	85.556	85.578	85.613	85.633	85.661	85.682

Table 71: Baseline and post development model results comparison

Comparison, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
720.4453	0.003	0.013	0.001	0.014	-0.001	0.000	0.001
700.7502	0.004	0.003	-0.017	0.020	0.002	0.000	0.001
674.009	0.006	0.002	-0.012	0.022	0.005	0.003	0.002
640.5771	0.005	0.003	-0.012	0.022	0.003	0.002	0.001
621.841	0.004	0.001	-0.017	0.021	0.000	0.000	0.000
588.8654	0.001	-0.003	-0.022	0.021	-0.003	-0.005	-0.005
542.6458	-0.017	-0.018	-0.037	0.021	-0.011	-0.016	-0.013
533.5641	-0.069	-0.056	-0.092	-0.028	-0.059	-0.054	-0.031
509.8936	-0.077	-0.057	-0.103	-0.042	-0.071	-0.062	-0.028
458.7506	-0.260	-0.185	-0.186	-0.124	-0.137	-0.104	-0.050
405.8468	-0.345	-0.321	-0.322	-0.185	-0.164	-0.108	-0.037
333.4546	-0.053	-0.062	-0.105	-0.007	-0.044	-0.034	-0.021
299.7251	0.002	0.002	-0.053	0.059	0.004	0.004	0.011
265.4841	0.001	0.002	-0.059	0.064	0.003	0.003	0.007
255.7566	0.002	0.002	-0.057	0.063	0.005	0.004	0.014
233.6861	0.001	0.002	-0.059	0.064	0.006	0.005	0.007
195.3342	0.001	0.001	-0.039	0.028	-0.010	-0.007	0.003
142.1153	0.001	0.001	-0.039	0.028	-0.010	-0.007	0.003
96.53466	0.001	0.002	-0.033	0.019	-0.023	-0.014	-0.003
64.28348	0.000	0.002	0.016	0.052	0.040	0.026	0.004
32.86087	0.000	0.002	-0.006	0.035	0.006	0.002	0.000
2.843554	-0.001	0.001	-0.024	0.022	0.002	0.002	0.000
691.5114	0.001	0.001	-0.039	0.028	-0.010	-0.007	0.003
677.9626	0.001	0.001	-0.041	0.028	-0.011	-0.006	0.003
646.0128	0.000	0.001	-0.041	0.028	-0.011	-0.007	0.003
615.4745	0.000	0.000	-0.040	0.028	-0.011	-0.007	0.003
580.297	0.000	0.001	-0.037	0.024	-0.010	-0.007	0.003
525.459	0.002	0.001	-0.036	0.025	-0.010	-0.005	0.003
489.5052	0.001	0.001	-0.048	0.033	-0.013	-0.007	0.004
457.2503	0.001	0.001	-0.050	0.033	-0.014	-0.008	0.004
427.8289	0.001	0.001	-0.051	0.034	-0.014	-0.008	0.004

Comparison, mAOD							
Cross-section	**50% AEP**	**20% AEP**	**10% AEP**	**5% AEP**	**2% AEP**	**1% AEP**	**1% AEP + cc**
404.8746	0.001	0.001	-0.054	0.035	-0.015	-0.008	0.004
379.6279	0.002	0.001	-0.056	0.036	-0.016	-0.009	0.004
355.6248	0.002	0.001	-0.057	0.037	-0.016	-0.009	0.004
311.3604	0.004	0.005	-0.057	0.044	-0.014	-0.008	0.007
281.7511	0.002	0.004	-0.058	0.045	-0.014	-0.007	0.007
262.976	0.002	0.002	-0.061	0.045	-0.019	-0.012	0.002
245.401	0.002	0.002	-0.061	0.044	-0.018	-0.011	0.003
218.3194	0.002	0.002	-0.062	0.046	-0.018	-0.012	0.002
197.138	0.002	0.003	-0.065	0.048	-0.019	-0.012	0.002
181.0515	0.001	0.002	-0.066	0.047	-0.019	-0.012	0.003
173.2393	0.002	0.002	-0.066	0.048	-0.020	-0.013	0.003
147.8697	0.001	0.002	-0.052	0.038	-0.015	-0.009	0.000
131.2385	0.001	0.002	-0.053	0.039	-0.015	-0.009	0.001
107.4533	0.001	0.001	-0.042	0.031	-0.013	-0.008	0.001
46.73948	0.001	0.001	-0.039	0.028	-0.012	-0.007	0.001
12.9441	0.001	0.002	-0.042	0.030	-0.012	-0.007	0.001